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Protocol Development: Criteria and Standards for Potable Reuse and Feasible Alternatives

Report of Workshop Proceedings
Warrenton, Virginia, July 29-31, 1980

SCS Engineers
Reston, VA

Prepared for

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Airlie House
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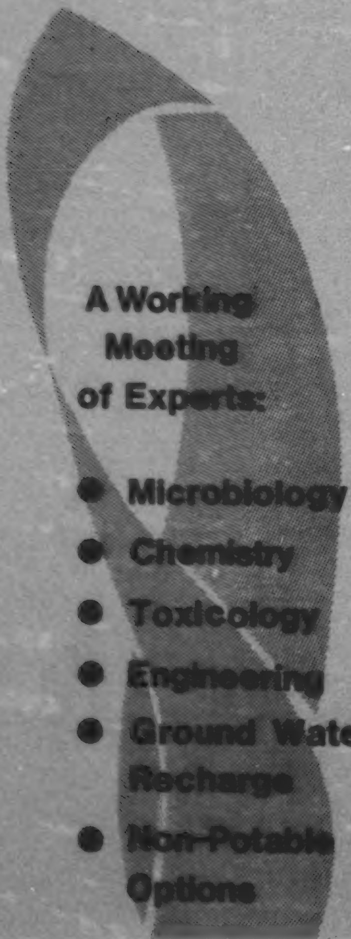

A Working
Meeting
of Experts:

- Microbiology
- Chemistry
- Toxicology
- Engineering
- Ground Water Recharge
- Non-Potable Options

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REPORT OF WORKSHOP PROCEEDINGS

PROTOCOL DEVELOPMENT: CRITERIA AND STANDARDS FOR POTABLE REUSE AND FEASIBLE ALTERNATIVES

Warrenton, Virginia
July 29-31, 1980

Sponsored by:

U.S. Environmental Protection Agency
Office of Drinking Water
Washington, D.C.

Conference Chairmen: Joseph A. Cotruvo
Frank A. Bell, Jr.

Prepared by:

SCS ENGINEERS
11260 Roger Bacon Drive
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December 1982

Preface

The National Primary Drinking Water Regulations were established on the premise that the source water would be relatively pollution-free and these standards were never intended to be comprehensive for determining the adequacy of the reuse of wastewaters for potable purposes. The purpose of this workshop was not to develop specific criteria and standards but to provide guidance with respect to approaches, problems, solutions and needed research or investigations for establishing a pathway to protocol development for potable reuse criteria and standards and for consideration of non-potable options. Development of potable reuse criteria and standards remains one of the challenging and critical environmental objectives of our time and non-potable options merit increase national attention.

With repect to potable reuse, the national need may be small by limited geographical areas may have urgent requirements. Non-potable options may often be used to help meet urban water supply requirements, thereby freeing higher quality water for potable uses.

This meeting brought forth a commendable participation from representatives of various technical areas and institutional backgrounds. The Office of Drinking Water is indebted to the workshop's panel of experts, speakers, work group chairmen and discussants, moderators and other participants for making this a forward looking and productive meeting.

The "Report of Workshop Proceedings," contains presentations by representatives from local, State, federal and international government agencies, consultants and universities. The first section includes introductory papers to outline the broad issues. In the second section the six work groups present their reports and revised issues papers with conclusions and recommendations regarding protocol development for potable reuse criteria and standards, and non-potable options. For each work group an issues paper was prepared before the meeting and served as a basis for discussions at the meeting. The work groups (chairmen) were:

Toxicology (Robert A. Neal)

Chemistry (Irwin (Mel) Suffet)

Microbiology (Richard S. Englebrecht)

Engineering (Russell L. Culp)

Ground Water Recharge (Paul Roberts)

Non-Potable Options (Jerry Gilbert)

The last section highlights a panel discussion on the question: Where do we go from here? Conference concluding remarks were offered by C.C. Johnson, Jr., of C.C. Johnson and Associates, Silver Spring, MD.

Acknowledgements

First recognition must go to the panel of experts who advised EPA on the planning and conduct of the workshop and helped to interpret results. They were:

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Assistance in the planning and management of the meeting was provided under contract by SCS Engineers of Reston, VA. The SCS effort was lead by Curtis Schmidt as technical consultant, E.T. Conrad as project director, and William Hassett as project manager; other staff included Don Shilesky, Jill Robertson, Debbie Bradshaw and Charlene Higgins.

Key members of the Office of Drinking Water headquarter's staff provided services beyond those recognized elsewhere in this document to help develop and conduct the meeting as follow:

Frank A. Bell, Jr., Planning Chairman; Hugh Hanson; Charles Hendricks; Gloria Ruggiero; and Patrick Tobin.

Cooperation in planning and conducting of this meeting was also received from Interior's Office of Water Research and Technology, the National Science Foundation, the U.S. Army Medical Bioengineering Research and Development Laboratory and from a variety of other EPA offices including the Office of Research and Development and the Office of Water Program Operations.

EXECUTIVE SUMMARY

F.A. Bell and Joe Cotruvo
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401 M Street Southwest
Washington, DC 20460

Protocol Development: Criteria and Standards for Potable Reuse and Feasible Alternatives

Executive Summary

F.A. Bell and J.A. Cotruvo

Introduction

A repeated thesis for the last 10 to 20 years has been that advanced wastewater treatment provides a water of such high quality that it should not be discharged but put to further use. This thesis when joined to increasing problems of water shortage, provides a realistic atmosphere for considering the reuse of wastewater. However, at this time, there is no way to determine the acceptability of renovated wastewater for potable purposes. National standards for drinking water quality are based on the use of raw waters from the highest quality source, and therefore, are not considered adequate when using treated wastewater as a source. In addition, factors of time, dilution and natural purification (such as in reservoirs), provide a degree of protection for existing water supplies against the acute threats of chemical spills and microbiological contamination, a protection which may not be present in direct potable reuse systems. Consequently the development of criteria and standards for potable reuse is becoming increasingly important. Further, elements of various federal legislation, including the Safe Drinking Water Act, provide for attention to the health implications involved in the reclamation, recycling, and reuse of wastewaters for potable supplies.

Key recommendations emanating from this meeting were for the following:

- Development of comprehensive standards and criteria to define potable water regardless of source.
- Undertaking a detailed characterization of potential sources of reclaimed water covering variability, frequency and concentration ranges for the various contaminants.
- Undertaking a major effort to examine unknown or inadequately known organic chemical components.
- Conduct of toxicological concentrate studies as a key element in a decision-making protocol involving many factors.
- More stringent microbiology requirements.
- Serious consideration of ground-water recharge options for potable reuse.

- Serious consideration of non-potable reuse options for extending available public water supply.

Development of actual criteria and standards for potable reuse involves the consideration of possible health risks, economics and legal, institutional and social considerations as well as the scientific and engineering aspects. Ultimately, therefore, such development is a policy determination based on many factors. However, development of basic protocol for answering the scientific and engineering questions associated with potable reuse is a scientific and technical matter. For this latter purpose, EPA called together the most expert and knowledgeable people in the pertinent scientific and engineering disciplines to plan, present and participate in a working meeting, "Protocol Development: Criteria and Standards for Potable Reuse and Feasible Alternatives."

The purpose of the meeting was not to develop specific criteria and standards but to provide guidance with respect to approaches, problems, solutions and needed research for establishing a pathway to protocol development for potable reuse criteria and standards and for consideration of non-potable reuse options. Approximately 110 people representing a wide range of scientific and technical expertise and coming from diverse institutional backgrounds -- federal, state and local governments, consulting, professional associations, academic, manufacturing, private and environmental organizations -- participated and assisted with the work of this meeting.

Statement of Concerns

An analysis of the various perspectives and factors that have existed over the years relating to potable reuse and feasible alternatives demonstrates several general areas of concern:

Divergent philosophies can provide a substantial area for debate whenever potable reuse is considered. One side which suggests a hierarchy of water use would give priority attention to using and maintaining the cleanest sources and exhaust non-potable options before considering potable reuse. Such attention would be given to preventive public health that potable reuse would not be considered until all other options including conservation and dual water systems, were exhausted.

Another philosophy sets forth definitional problems. It indicates that reuse already exists in many major water supplies through use of polluted surface water streams.

Consequently
potable reuse should be defined to include both direct and indirect reuse, as from a river or other polluted source. This approach goes on to make the point that current advanced wastewater treatment (AWT) technology already produces effluents which can meet national primary drinking water standards. While this approach was not adopted at the meeting, it has still been a point of serious consideration and could result in application of direct potable reuse with the addition of monitoring, operation and maintenance requirements.

Possible pathways for achieving satisfactory criteria and standards for potable reuse would be charted through these opposing philosophies.

Economic and social considerations will always be important to decisions about potable reuse but should not necessarily affect the scientific and engineering aspects of protocol development for potable reuse criteria and standards. While various studies have shown the national need for potable reuse to be less than one percent, there are still limited areas (for example, southern California, Denver) where the need for potable reuse may be intense and competitive in cost with alternatives.

In some cases of intense economic justification for potable reuse, non-potable options are sometimes considered either too unwieldy or expensive to accomplish; development of new fresh water sources and/or conservation options may be unavailable. A series of institutional and legal blocks such as water rights law, may also act to prevent the utilization of options other than potable reuse or may negate any form of reuse as a viable option.

The social acceptability of using renovated wastewater for potable purposes must also be considered. A variety of studies and papers have addressed this subject; these were summarized in one of the introductory papers to this meeting.

Public health protection in the application of planned direct reuse and in existing indirect reuse situations represented the keystone for meeting deliberations. Since many indirect reuse situations already exist and require no fresh decisions at this time, the meeting was principally focused on problems relating to possible new potable reuse ventures including ground-water recharge and various engineering systems for accomplishing potable reuse. Areas of concern in criteria and standards development are outlined as follows:

Chemistry

A principal concern related to the definition of the variability, frequency and range of concentrations of inorganic and organic chemicals present in the raw wastewater source. Assessing the impact on criteria and standards development from the known and unknown components presents additional complexities. The limitations and potentials of sampling and analytical technology to provide the needed information necessitates exploration with consideration being also given to possible surrogate analytical methods and the conjunctive use of a series of measurements. Measurement technology should also be developed for the inadequately known organic chemical components. Monitoring strategies to evaluate the efficiencies and reliability of various treatment systems to remove chemicals of health concern must also be addressed. With particular reference to unknown organic fractions, the availability and/or potential development of acceptable concentration methods to provide materials for toxicological testing ranks as a key interdisciplinary matter with the toxicologist. Finally, the impact of water treatment chemicals in forming potentially harmful or toxic by-products and possible development of alternate methods to minimize or avoid this problem should be considered.

Toxicology

The broad scope of acute and chronic health risks as related to known chemicals in wastewater and their impact on criteria and standards development requires exploration. Means including *in vivo*, *in vitro* and combination/surrogate testing, of defining the toxicity potential of the unknown organic fractions present in reuse water ranks as a number one priority. Preparation and evaluation of the organic concentrate with respect to its stability and utility in a toxicity testing protocol are critical problems. Epidemiology aspects also should be considered when appropriate, but this would often be prospective. Side-by-side studies, comparing the toxicity of pristine natural waters, indirect reuse waters and direct reuse waters would be highly instructive.

Microbiology

The potential health threat from various microbiological contaminants - viruses, bacteria, protozoa, parasites - through potable reuse processes requires examination. The potential impact of treatment technology in meeting microbiological objectives must be considered along with the potential for using alternate disinfectants to chlorine. The validity of traditional indicators and possible approaches for development of microbiological criteria and standards for potable reuse must be addressed.

Engineering

Engineering deals with the various physical treatment systems (direct once through; direct repeated recycling; simulated indirect reuse) for processing wastewater for possible potable reuse. The strengths and weaknesses of these systems and their potential impact on criteria and standards development need to be addressed. Monitoring and process control and means of assuring reliability of plant performance require examination. The role of source control in regulating wastewater quality should be considered. Finally, the important role of pilot plant testing for various approaches must be examined as a key factor in development of criteria and standards.

Ground-Water Recharge

Feasible alternatives of ground-water recharge (deep well injection; surface spreading and infiltration; the dedicated basin approach) should be evaluated, along with their potential impacts on contaminant transport and transformations. Source control, process control and limitations in monitoring should be addressed by focusing on contaminants that are likely to be mobile and persistent in the environment. The unique strengths of ground-water recharge should be taken into account when developing and implementing potable reuse criteria and standards.

Non-Potable Reuse Options

Non-potable reuse represents an important alternative in total water resources management and a means by which public water supplies can expand their total availability of water for domestic use. The feasible non-potable options together with criteria for decision making regarding potable/non-potable options needs to be addressed. A review of health/esthetic criteria and standards for non-potable options is most important.

KEY FINDINGS OF THE WORK GROUPS

The following findings represent the key ideas and approaches emanating from the six technical issues papers and work group deliberations:

Toxicology

Prevention of excessive exposure to inorganic, radiologic and particulate substances can generally be handled by setting maximum contaminant levels (MCLs) and by application of appropriate treatment technology. However the management of risks from organic substances presents more complex problems. Where adequate information is available on specific organics of concern, additional MCLs should be set. With respect to the non-MCL and unknown organic fractions an innovative approach was recommended:

1. Concentrate studies with mixed organics: concentrate studies should be performed not only on the proposed reuse water but also on a series of controls -- unconcentrated distilled water and organics concentrated from both a relatively pure ground-water source and from a municipal drinking water system known to be subject to municipal, industrial and agricultural pollution. The organics in the water should be concentrated 1,000-fold and the concentrate should represent the organics originally present and not be subject to serious chemical or other transformations. Many problems remain in producing a stable organic concentrate which will be representative of the organics originally present in the reuse water. Toxicity tests should be conducted for subchronic effects, chronic effects, teratogenicity, reproduction, mutagenicity, carcinogenicity and immune system effects. Animal tests would be conducted by oral ingestion or gavage.

   Results of the concentrate studies would provide the responsible governmental offices with an important segment of basic data for the acceptance or rejection of waters proposed for potable reuse or to require the provision of additional treatment prior to the retesting.

2. A second set of data would be provided by epidemiologic studies. These data will be subject to sensitivity limitations and should only be considered as supplementary to toxicologic data.

3. The highest research and development priority was assigned to the provision of a representative organic concentrate for use in toxicological testing. The technique would have to be capable of concentrating thousands of gallons per day in order to provide enough material for the toxicology tests.

Chemistry

Specific analytical methods exist for 114 specific organic priority pollutants and for other designated organic contaminants in drinking water. Analytical quality control has been established for these contaminant analyses and is being tested. However, many more specific organic contaminants remain without systematic methodology or quality control procedures. Broad spectrum analysis to determine the presence of many organic chemicals simultaneously is needed on a routine basis to help define the presence and variability of these components.

The available chemical data base for reuse waters remains sparse and is not well documented. Information about non-volatile organic compounds is almost non-existent and many other organic compounds have been identified but not adequately quantitated. Major effort should be made to examine the unknown or inadequately known organic fractions including broad spectrum analytical protocols and liquid chromatographic screening methods for non-volatile pollutants. The present and future data base requires development and evaluation with respect to variability in source water concentrations, treatment process removal efficiencies and concentrations delivered to the consumer. Monitoring and computer accessing of the data base needs to be developed.

Non-specific organic analyses can be defined in terms of specific goals -- as surrogate parameters; as aides in unit process design; for monitoring unit processes; and for plant operational control. Currently no surrogate parameters can be suggested as a substitute for specific organic constituents of health concern but the total organic halogens (TOX) method appears to hold the most promise. For cost effective operation of a reuse facility, it is projected that non-specific procedures in conjunction with broad spectrum analysis and chromatographic profiles could probably be used for operational monitoring and control. Specific analyses could be conducted as a part of the basic chemical characterization or to check excursions of the method.

In terms of preparing organic concentrates, there is currently no single procedure that is capable of concentrating all the organics for optimum toxicity testing, or even for analytical testing. A system to remove and concentrate different organic groups by varying techniques was considered so that a representative sample could be made available to the toxicologist. A state-of-the-art method for development and evaluation is suggested for testing.

- Isolate volatiles - quantify by the purge and trap method and reconstitute.

- Isolate non-polar and low molecular weight organics - use XAD-2 resin.

- Isolate humics and polars - use XAD-8 or reverse osmosis.

- Isolate humics and others - use reverse osmosis.

- Isolate intermediate molecular weight range - methods need development.

Since a number of complicating factors, such as artifacts, concentrate stability, organic-inorganic interface, overlap and others, may be present, these approaches should be carefully evaluated in parallel and in series.

Basic information about inorganic chemicals in reuse water is more complete than for organics and a monitoring strategy for inorganic chemicals could be developed which should meet public health objectives. A mathematical analysis of repeated reuse recycling demonstrates that an infinite concentration buildup for some unknown constitutent would not occur but that such a buildup would be subject to a steady state situation depending principally on the chemical input during each recycle, the percent removed in treatment and the degree (percent) of recycle.

Microbiology

Proposals for direct potable reuse require a complete re-evaluation of the means for biological control. There should be no detectable pathogenic agents in potable reuse water. Potable reuse requires stricter microbiological standards, including quality control monitoring, than the current national coliform MCLs for drinking water. However, specific criteria for viruses, protozoa, helminths and some bacteria are currently impracticable because of varying source water densities and because of inadequacies in detection and enumeration methods for these organisms.

Available treatment technology appears to be capable of meeting any microbiological requirements but this does not remove the need for analytical confirmatory data nor the need to insure operational integrity of treatment systems. Reliable monitoring must be available and vigorously used.

Research recommendations include developing better information on disinfection, developing or improving analytical methods for viruses, protozoa, helminths and some bacteria in water, better definition of microbiological characteristics of raw wastewaters and other elements which would support a satisfactory program for implementing potable reuse. Special attention should be given to examining the validity and utility of existing surrogate measurements and to developing new indicators with a goal of real-time monitoring.

Engineering

Areas considered in workshop deliberations included: quality of source; storage prior to treatment; specification of treatment processes and design criteria; process redundancy requirements; parameters affecting plant process control and operation; types and frequencies of sampling and monitoring for plant control; storage of treated water prior to use (recharge or surface reservoir); and operation and maintenance criteria.

In considering the various available treatment systems and approaches, it was felt that treatment technology does not appear to be a limiting factor and that maximum flexibility should be allowed in treatment designs so that the most cost effective approaches can be implemented which will meet health requirements, including fail-safe operation.

Comprehensive standards and criteria should be developed to define potable water regardless of source. However, because present national drinking water standards are not intended for direct potable reuse waters, comprehensive standards and criteria should include specific requirements for direct reuse applications:

- monitoring of source quality, the frequency to vary with source quality.
- the setting of limiting concentrations with provision for acceptance or rejection of the water at various points in the treatment process to be determined on a case-by-case basis.
- provision for pilot plant studies to determine treatment and reliability requirements prior to plant design.

Storage of treatment plant influent can be advantageous for flow equalization, blending, plant reliability, spill and upset mitigation or for other reasons. Protected storage of plant effluent can be helpful in providing lead time for monitoring and controlled diversion in event of plant breakdown.

Operating and maintenance criteria are critical. Operation and maintenance and operator training manuals should be provided prior to plant start-up. Separate operator certification programs for a new class of potable reuse plant operators should be considered along with specific minimum qualifications for plant operators and supervisory personnel.

Thorough characterization of potential source waters for potable reuse was a major research recommendation involving:

- Source waters for evaluation should be selected from water short areas and priority attention should be given to imminent need locations.
- The characterization of source waters should be accomplished by using the limits of measurement technology as contrasted to measuring only drinking water MCLs and the listed priority pollutants.
- Multiple samplings should be performed to establish frequency of occurrence, variability and calculated ranges over time for the various contaminants.

Ground-Water Recharge

Important benefits can be obtained by ground-water recharge. In addition to providing an economical means of storage with reduced evapotranspiration, subsurface passage removes some contaminants and retards the movement of others by means of filtration, biodegradation, volatilization, sorption, chemical precipitation, and ion exchange. Its use as part of a system to produce potable reuse water is encouraged.

With respect to the transport and transformation of contaminants in the subsurface environment, the following table summarizes the current state-of-knowledge with respect to the ability to predict impacts of ground-water recharge projects in such a way as to protect the resource for future use. This table pinpoints organic and virus aspects as requiring priority research attention.

Contaminant Class	Adequate Knowledge	
	Yes	No
Major cations and anions	X	
Particulates	X	
Nutrients (nitrogen & phosphorus)	X	
Metals	(X)	
Organics		(X)
Microbiological pathogens		
bacteria and protozoa	(X)	
viruses		(X)

(The enclosing parentheses indicate that the categorization is especially subject to uncertainty.)

A combination of pre-recharge treatment and natural ground-water basin treatment can be used to minimize the need for treatment after extraction. Various treatment-recharge-treatment systems are possible but any system involving the application of waters containing certain classes of contaminants, the behavior of which in the subsurface environment is not adequately understood, should be conducted only for research and demonstration purposes. Dedicating all or parts of ground-water basins to recharge should be explored as a means of long-term management. All ground-water recharge projects must be adequately monitored to confirm performance within appropriate design criteria and standards. However, real-time monitoring is not essential if sufficient residence time in the subsurface is assured.

Non-Potable Reuse Options

In the United States there are now more than 500 successful wastewater reuse projects utilizing non-potable options: such options are the preferred method of reuse and should be considered in the decision-making process before the potable reuse option. However, a variety of steps need to be taken before non-potable options can be given maximum utilization:

- Non-potable options should be considered as a part of the overall water resource in terms of planning and implementing major projects.
- Water reuse is included in the legislation, regulations and programs of several federal agencies. While cooperation has been good, an improved national focus is still needed.
- Industrial recycling has potential for much greater reuse and should be encouraged through federal support of engineering studies regarding optimum water recycling within each of the major water using industries.
- Agricultural recycling has many proven benefits and should be given greater attention as a water management alternative.
- Consistent and comprehensive national public health guidance should be provided for the various categories of non-potable reuse where there are public health concerns.
- A manual of current practice should be developed based on the existing experience regarding the design, operation and maintenance of reuse systems (a manual currently under development by the Water Pollution Control Federation may fill this need).

- A comprehensive informational guide on the economics and financing of reuse systems should be prepared and disseminated.

KEY MEETING CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the various workshops, and the ideas and approaches advanced by the various speakers, panelists and other participants, the key meeting conclusions and recommendations are summarized as follows.

1. Comprehensive Criteria to Define Potable Water

A major objective should be the development of comprehensive standards and criteria to define potable water regardless of source. Since the present national drinking water standards are incomplete for direct potable reuse and will undoubtedly require upgrading for indirect potable reuse, additional research and investigation will be required to attain a satisfactory level of comprehensiveness. Supplementary criteria are also needed for monitoring, operational reliability and limiting concentrations for determining acceptance/rejection at various treatment points.

2. Characterization of Potential Reuse Source Waters

Since the data base is sparse, a thorough characterization of potential source waters, giving priority attention to imminent-need areas, for chemical and microbiological constitutents should be accomplished. The characterizations using all available analytical methodology as contrasted to measuring only priority pollutants and the like, should be performed as multiple samplings to establish frequency of occurrence, variability and calculated ranges over time for the various contaminants.

3. Unknown Organic Chemical Components

A substantial portion of the organic content of wastewaters is either entirely unknown or inadequately quantitated. Information about non-volatile compounds is almost non-existent. Major effort should be made to examine the unknown or inadequately known organic fractions, including monitoring, broad spectrum analytical protocols, liquid chromatographic screening methods for non-volatile pollutants and development of a data base which can be readily accessed.

4. Toxicology Concentrate Studies

With respect to delineating the unknown chemical components and the assemblage of a satisfactory data base, it was felt that this may prove to be an evolving technical problem that nevertheless should be tackled. Toxicology/concentrate studies may prove to be a key element in a decision-making protocol involving many factors. Specifically, a 1000-fold mixed organic concentrate from the potential reuse water, along with three controls would be used for comprehensive toxicological testing. However, no single concentration procedure is capable of concentrating all of the organics; several systems along with a potential list of complexing factors, such as the time-flow stability of the concentrates, are suggested as priority items for investigation and evaluation. This area obviously is one that should receive continuing attention from toxicologists, chemists, and decision-makers.

5. Microbiological Requirements

Current treatment technology appears to be capable of meeting any microbiological requirements but this does not remove the need for analytical confirmatory data nor the need to insure operational integrity of treatment systems. Any train of treatment elements, selected to meet microbiological requirements on a case-by-case basis, should be backed-up by reliable monitoring, using available methodology, for the key microbiological factors and this monitoring should be rigorously applied. There should be no detectable pathogenic agents in the potable water.

6. Ground-Water Recharge

Important benefits, including storage, reduction in contaminants and others can be obtained by ground-water recharge and its use as part a potable reuse system is encouraged. Various treatment-recharge-treatment systems are possible, especially in a dedicated basin mode, but recharge with waters containing contaminants whose behavior is poorly understood in ground water should be conducted only for research and demonstration purposes.

7. Non-Potable Reuse Options

In the decision-making process, non-potable options should be considered ahead of potable reuse and should be factored into overall water resource planning and implementation programs whenever this can result in improved efficiency and lower overall cost. A strengthened focus needs to be provided for water reuse activities and consistent and comprehensive national public health guidance should be developed for the various categories of non-potable reuse where there are public health concerns.

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INTRODUCTION: WHAT ARE THE ISSUES?

Lloyd C. Fowler [1]

I am honored to participate in this group of scientists and engineers gathered to discuss potable water reuse. Over seven years ago some water purveyors started a California Association of Reclamation Entities of Water to further water reuse as a means to extend the communities water supplies. We named it that so we could call the Association Watercare. It turned out that name was already copyrighted. We tried Aquacare, H_2O Care all to no avail. Its been CAREW for years now and still is a viable force in California's water reuse program. The Seventh Annual Conference of CAREW was just completed in June at the University of California at Santa Barbara.

CAREW started to move to support one water quality standard regardless of source. We got a lot of government and public service agencies to agree with this concept and we talked of this to EPA and our Congress people. Perhaps this activity helped to set in motion the ideas that lead to this Symposium.

Anyhow, people are now talking about potable reuse in spite of all the problems we can conjure up. This morning we are to consider the issues.

What are the issues in potable reuse? As I see it there are two: Need and Quality. Is there a need for potable reuse? Can we assure protection of public health?

First the Need. There is a need where water is in short supply. This includes many parts of the world as well as the United States. While alternative schemes for non-potable reuse can free water for potable use, the development of potable reuse extends the community water supply further. It eliminates the need for dual distribution systems and the worry over cross-connections.

The Need issue also involves social aspects of supply and demands versus environmental concerns. If we provide for complete (potable) reuse there will be a reduced need for additional community water supply projects. Of course, the public must be willing to accept potable reuse as a water supply for themselves. Survey after survey indicates more willingness to do so as water supplies become scarcer and our environmental awareness grows.

Yes, there is a need, and there is a need for this Symposium.

---

[1] General Manager and Chief Engineer, Goleta County Water District, California.

Next the Quality. Our desire to protect the public health is obvious. The quality of the water supply sources used to serve domestic customers ranges from hardly any pollution to grossly polluted. Rain contains the pollutants washed from the air. Surface waters contain the pollutants washed from or dumped on the watershed. Ground waters contain the pollutants leached from dumps and the rock materials of the basin. Yet we believe we impose no undue risk to public health with the current drinking water standards.

Can these drinking water standards be used to decide whether or not reclaimed waters are safe for domestic potable uses? No, say public health authorities. Why? Because they were not intended to cover every possible health concern. If the present standards are adequate for the present range of water supplies, then there must be some comparable set of standards that will be adequate for potable water reuse. If we can use indicator organisms and key chemicals in defining adequacy of todays drinking water, then there must be a similar set for reclaimed water. The challenge is to find the indicators, the keys, if they are not already known, and use new measures of reliability. When we have accepted these we will have a set of truly adequate drinking water standards.

Unfortunately, people can dream up problems to be used as reasons for not doing anything faster than industry can develop new chemical compounds. As one sage put it a few years ago: "We resolved the water reuse problems of bacteria, of virus, of heavy metals and now they come up with a concern over organics in trace amounts too small to be measured accurately. When we solve that problem there will be a new one of trace Ongerths." This is a California Bureau of Sanitary Engineering joke - now that Henry O has retired we may look forward to trace Gastons? These two guardians of public health are right in their careful positions of caution. They must be listened to.

But we do not need to stop working on reuse waiting for some unknown to pop up. Real time water quality monitoring as demonstrated by NASA and EPA is the solution to reliability and adequate treatment. Ground water recharge with reclaimed water followed by treatment at the point of extraction, if needed, can further increase the safety factor.

Again these are some of the aspects of the main issues: Need and Quality. The subsets of these are numerous small issues that relate directly to need and quality. The presentations that follow will illustrate this and amplify the problems - maybe even present some solutions. Let us hear what others have as selected issues.

PHILOSOPHY OF THE SAFE DRINKING WATER ACT AND POTABLE REUSE

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PHILOSOPHY OF THE SAFE DRINKING WATER ACT AND POTABLE REUSE*

by

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The charges to me to discuss the "philosophy" involved in obtaining safe drinking water, to review the relevant public health history, principles and policies, and to outline public health considerations regarding reuse are certainly congenial to one who has been joined in the battle for water quality for more than four decades. More importantly, the rapid developments in science and technology, and more particularly in analytical chemistry and toxicology, require that these more difficult substantive issues be left to younger colleagues while I enjoy the liberty of commenting on the general scene.

The philosophy that might guide us in helping provide safe water where resources of water are being stretched, and where threats to its quality from a hyperactive chemical industry are constantly growing, can be summarized in an old-fashioned term: the sanitary survey. Sanitary surveys, which were mandated in the US Public Health Service 1962 Drinking Water Standards, placed emphasis on identifying sources of pollution rather than solely monitoring and analysis. The operative statement in those standards was that "The water supply should be obtained from the most desirable source which is feasible, and efforts should be made to prevent and control pollution of the source."

In the EPA National Interim Primary Drinking Water Regulations of 1976, this concern for the quality of the source is found only in the appendix but, even here, the guidance is clear: "Production of water that poses no threat to the consumer's health depends on continuous protection. Because of human frailties associated with protection, priority should be given to selection of the purest source. Polluted sources should not be used unless other sources are economically unavailable, and then only when personnel, equipment, and operating procedures can be depended on to purify and otherwise continuously protect the drinking water supply."

These strictures that give priority to developing the purest source are not at all stressed in the Safe Drinking Water Act, nor do they appear to be an essential element of EPA or regulatory concern. Major attention is given to maximum contaminant limits, monitoring, and even treatment, but very little attention is given to protection of the source, selection of the purest source, or the institutional measures that would provide assurance of continuous protection. For example, 95% of the more than 60,000 community water supply systems in the US serve fewer than 10,000 people.(1) There is no question but that the "personnel, equipment and operating procedures" afforded by such systems cannot be depended upon to provide continuous protection. Only regionalization of water supply services can offer much hope that small communities can be assured a high quality water service but the Safe Drinking Water Act is not at all explicit, nor are EPA or the states active, in promoting regionalization.

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*For presentation at the Environmental Protection Agency Symposium on Protocol Development: Criteria and Standards for Potable Reuse and Feasible Alternatives, Warrenton, Virginia; July 29, 1980.

Prior to the 1962 Drinking Water Standards, the only concern in these Standards was with the quality of water. No regard whatsoever had been given to the adequacy of the supply. In other words, a cessation of supply would not have violated the Standards, although the health consequences would have certainly been troublesome. The committee that prepared the 1962 Standards succeeded in adding the following statement: "Approval of water supplies shall be dependent in part upon: ... Adequate capacity to meet peak demands without development of low pressures or other health hazards." Also added for the first time was a responsibility for conditions in the water supply system "...to the free flowing outlet of the ultimate consumer."

Unfortunately, the SDWA and the Drinking Water Regulations now in effect fail to address the adequacy of service, which is a serious problem to the customers of the tens of thousands of rural community water systems, who are more interested in water being available at the tap than in the MCL of some esoteric contaminant.

Characterization of Reuse

Water is one of our few renewable resources. It is reused continuously, thanks to the hydrological cycle powered by solar energy. Nature's water reclamation utilizes the most energy-intensive of all systems - distillation - but because solar power in this context is free and the most effective means for separating water from its impurities, we need not be too concerned with the appropriateness or the efficiency of the process.

Another form of reuse is ubiquitous, particularly in the industrialized countries of the world. It is the reuse that takes place when water is withdrawn for a useful purpose from a water course or lake into which used water is discharged. In arid areas, where water is used extensively for irrigation, it may be reused several times before it reaches the sea. By that time, it often becomes so saline that it is unfit for further productive enterprise without desalination.

A more widespread reuse practice, and that which concerns us here, is that which takes place in most of the rivers of the country where water supply for a community or industry is withdrawn from the upper reaches of the river and, after being used and substantially modified in quality, is discharged to the river which then serves as a drain but also as a source of water for the next community or industry downstream. A single river may serve many such communities and industries seriatum from its origins to its outlet. This has been termed *indirect reuse*, as contrasted with direct reuse where wastewater is piped directly to a user with appropriate treatment intervening.

Despite the admonitions in the Drinking Water Standards that a water supply to be used for potable purposes should be drawn from the most desirable source which is feasible, local authorities and their engineers have been quite happy to draw upon polluted rivers, and regulatory agencies seem not to have been concerned. There are good reasons for this. The earliest use of such rivers for water supply led to great epidemics of cholera and typhoid in the early 19th century. It was not until the mid-19th century, when Dr. John Snow made the connection between water and cholera, that such sources began to be looked upon with suspicion. The Lambeth Water Company in London moved its intake on the Thames from the metropolitan area to a point on the Thames upstream of London in 1847, and so protected its customers from the cholera epidemic of 1853 that ravaged the customers of competing water companies that continued to draw from the lower Thames.(2) Incidentally, the decision to move the intake upstream was taken before there was any *proof* that the water supply was responsible for cholera, in fact before the germ theory of disease had been developed. Acting before scientific proof was in hand was clearly the prudent approach, and well justified by events.

However, with the development of filtration and, more particularly, chlorination for disinfection, using a polluted river as a source of potable water no longer continued to pose the threat to health that these sources had been. Engineers and public health authorities were comfortable in the technology that had been developed. They believed, correctly, that any river, no matter how seriously polluted, could be made free of infectious disease organisms. And so, despite the principle that the wisest course of action is to use the purest water, many communities developed polluted sources and called upon water treatment technology to render the water safe. (Many communities, on the other hand, opted for protected sources despite the greater cost.) In particular, that characteristic of chlorine which permitted a chlorine residual to be maintained, and easily monitored, would assure water purveyors that, with adequate chlorine residual at certain temperature and pH, and after sufficient detention, a water could be assumed to be free from infectious disease organisms.

(Incidentally, many engineers who object to EPA's proposed use of a treatment technique to control organics in drinking water, rather than a maximum contaminant level, forget that the historic bacterial safety of our water supplies has never rested with the determination of maximum contaminant levels, but with the method of treatment. Determination of the bacterial content takes so long that a finding that a water is laden with bacteria can be made only after the water has been distributed and ingested. The safety lies in the treatment afforded, along with the presence of a chlorine residual.

Today, a substantial portion of the total population that is served from public water supply systems depends upon sources that comprise in part wastewaters that only hours or days earlier had been discharged to municipal and industrial sewers upstream. Because the drinking water regulations still emphasize bacterial safety (there is still no mention of viruses), water taken from such polluted sources can readily meet the standards, or at least that portion of the standards that speaks to maximum levels of bacteria. Such water does not satisfy that section of the standards that calls for utilization of the purest source. In fact, many engineers are today still recommending that such rivers be the choice for additional water supply for communities. Such has been the recommendation of the Corps of Engineers for additional water supply for New York City, proposing taking water from the Hudson River, the sewer of the State of New York. Up to now, New York City has only been using protected upland supplies. Asheville, North Carolina, high in the Blue Ridge mountains, which up to now has been taking its water from completely owned upland watersheds, is being urged by its engineers to take its additional water from the French Broad River, which is subject to heavy urban and industrial pollution. Why, in fact, do we need to be concerned about using such polluted sources if water can be treated to meet the Drinking Water Regulations, at least that portion of the Regulations that speaks to maximum contaminant levels?

The reason is clear from the history of the Safe Drinking Water Act and its concern for the development of maximum contaminant levels for chemicals not mentioned in the Interim Drinking Water Regulations. The Drinking Water Regulations contain MCLs for ten inorganic chemicals and only six organic chemicals, in addition to turbidity, bacteria, and radionuclides. The stimulus for the passage of the SDWA came from the detection of scores of synthetic organic chemicals in the Mississippi River at the New Orleans intake. (That the finding of these myriad chemicals at the mouth of the Mississippi should be a surprise is itself surprising. The most casual sanitary survey, one which required no more than a glance at a map of the Mississippi River watershed, would show that it drains water and concomitant waste materials from all or portions of more than half the states in the union and some part of Canada. To have found few chemicals in the water would have been the surprise.)

The Chemical Revolution

World War II saw the beginning of the "chemical revolution", the development of synthetic organic chemicals. Some 63,000 chemicals are already in commerce, and others are coming into use at the rate of 1,000 a year.(3) Many of these chemicals are formulated to be long lasting and therefore are not readily degraded. They find their way into the aquatic environment and into drinking water supplies through many routes: agriculture, industry, urban runoff, and the home. Those wastewaters that are sewered and treated are the most tractable. Those wastes that are characterized as being present in "nonpoint" sources, reaching water courses through overland runoff from farms and construction sites, from industrial sites, from roadways and urban streets, and from landfills and toxic chemical dumps, are less tractable. The sulfur and nitrogen oxides discharged from industrial and power plant stacks and from vehicles results in acid rain which has had a serious impact, not only on many eastern lakes, but by adding to the leaching power of rainfall and stormwater runoff, thereby carrying greater concentrations of polluting chemicals into our water courses.

Some 20 years ago, in a comprehensive paper on cancer hazards, Dr. W. C. Hueper of the National Cancer Institute stated:

> "It is obvious that with the rapidly increasing urbanization and industrialization of the country and the greatly increased demand placed on the present resources of water from lakes, river, and underground reservoirs, the danger of cancer hazards from the consumption of contaminated drinking water will grow considerably in the foreseeable future."(4)

It is beyond the scope of this paper to recite the data on the presence of synthetic organic chemicals, as well as heavy metals, in our water courses; nor is this the place to summarize the epidemiological studies that have been mounted. Granted that each epidemiological study by itself is subject to criticism, the thrust of all of them is in one direction; that the long term ingestion of waters drawn from polluted sources has some deleterious impact upon health. It may very well be that, just as with radiation and asbestos, many decades will pass before the full impact of these organic chemicals in the aquatic environment is understood. However, is it necessary to wait for convincing scientific proof, or is it prudent for those responsible for providing safe water to assume, as the Lambeth Water Company did, that polluted sources are inherently more hazardous than protected sources?

Options for Protecting Water Supplies

The problem of dealing with synthetic organic chemicals, and other chemicals, that threaten the safety of water supplies used for drinking may be addressed in one of three ways:

1. Eliminating the chemicals at their source;

2. Monitoring and removing the chemicals by treatment; or

3. Avoiding the use of the polluted sources for potable supplies.

Eliminating Chemicals at the Source:

While this has been the goal of much of the legislation enacted during the 1970s, particularly the Federal Water Pollution Control Act Amendments of 1972, implementation to the point that discharges of pollutants would be eliminated has never been realistic. The mandated treatment does not address the synthetic organic chemicals of concern, even if the treatment is fully implemented. Even less amenable to control are the nonpoint discharges. The problem is exacerbated by the continual development of new chemicals. The General Accounting Office, in reviewing the status of control of chemical exposure in industry, concluded that "...it will take more than a century to establish needed standards for substances already identified as hazardous. ... The problem is compounded because new substances, which may warrant standards, are being introduced faster than standards are being established on existing substances."(5)

The consequences of urban runoff, the source of many of the contaminants in water courses that drain urban areas, can be appreciated from the parameters that are used: pounds of pollutant per curb-mile of street or per square mile of development. The greater the number of curb-miles of street or square miles of development on a watershed, the greater the pollution.

Corrective measures may reduce the impact, although studies have shown that the best such measures can reduce the pollutant level only on the order of 40 to 70%.(6)

Large rivers that are used as sources of water supply by some cities are natural drains. Materials that are used in the drainage area cannot readily be eliminated or intercepted. To declare a moratorium on the use of synthetic organic chemicals or the development of new ones would be to deprive society of chemicals that have important social benefits.

It can only be concluded that, in an urbanized and industrialized society, those waters that drain urban and industrial areas will inevitably contain large enough numbers of synthetic organic chemicals that either singly, or in combination, can be expected to have undesirable health consequences if ingested over a protracted period. While all feasible measures to control these chemicals should be taken, such measures cannot assure their absence in supplies drawn from the sources to which they drain.

Monitoring and Removing Chemicals by Treatment: If it is granted that the chemicals will find their way into surface and groundwaters, they might be monitored and removed in treatment. Unfortunately, adequate, reliable and economically feasible technology for routine monitoring and treatment for removal of synthetic organic chemicals is not yet available. Should routine monitoring become technically feasible, the cost would be far too high for the thousands of relatively small municipal agencies which are responsible for wastewater disposal and water supply. Instrumentation and personnel required would be costly and outside the reach of most local authorities. The installation of facilities and their proper operation to assure removal of these compounds and the necessary concommitant monitoring is not likely to be economically feasible, except in the largest cities. While efforts to identify and remove chemicals need to be made where populations are currently exposed, this approach cannot be depended upon for the long term, particularly for the more than 99% of water supply purveyors that serve under 50,000 persons each.

Avoiding the Use of Polluted Sources for Potable Supply: The last option and the only one which can give assurance, to the extent that such assurance is possible, that the population will be protected from the continuous ingestion of synthetic organic chemicals is to avoid using sources subject to significant urban and industrial pollution. Because upland sources that are suitable for water supply development and underground sources are limited, and constantly being threatened by urban and industrial growth, efforts need to be made to identify and preserve them for eventual water supply development, and to protect their quality by adequate land use planning and appropriate regulation. Protected upland sources and groundwaters can be exploited far more than they have been. For example, Vicksburg, Mississippi, changed its water supply from an intake in the Mississippi River to groundwater. However, protected sources are not likely to meet future demands for water supply everywhere, particularly if these waters are used indiscriminately for all the purposes now met by urban water supply systems. This is where the potential for reuse can minimize the exposure of populations to the synthetic organic chemicals in their water sources. If polluted sources or reclaimed wastewaters are used for the many nonpotable purposes now being met from potable supplies, then the limited protected sources can be conserved for potable purposes.

Even in areas where protected sources are limited in quantity, these supplies are now squandered on uses such as urban irrigation, industrial processing and cooling, toilet flushing, and car washing - uses that can be met with waters of much lower quality.

Nonpotable Water Reuse

The last of the three options for the protection of populations from the ingestion of synthetic organic chemicals may, in many instances, require nonpotable reuse, although many water purveyors have options for protected sources that have not been fully explored because there had been no appreciation of the importance of utilizing protected sources.

The hallmark for husbanding protected sources has been stated by the United Nations Economic and Social Council:

> "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade."(7)

Where protected sources are limited in amount, substituting reclaimed wastewaters for waters of potable quality that are now being used for nonpotable purposes, in other words "source substitution", can provide the following benefits:

1. The demand on high quality sources would be relieved so that such sources would serve larger populations;
2. The cost of providing reclaimed water for nonpotable purposes would be far less in many instances than the cost of development of additional high quality fresh water sources, even where these are available; and
3. The risk to the population of the lifelong ingestion of synthetic organic contaminants in polluted water would be virtually eliminated.

Potable Water Reuse

Potable reuse, the piping of sewered wastewaters directly into a water supply system, albeit with extensive treatment, suffers from the deficiencies of the first two options mentioned above.

Were the wastewaters to be constituted solely of biodegradable organics of human origin, with nondegradable chemicals eliminated at the source, it might be feasible to convert such wastewaters into a potable water without too much concern for the presence of chemical contaminants. However, urban residential communities, even in the absence of water-using industries, contribute significant concentrations of a wide range of synthetic organics to the sewer system.

Every home today is a virtual pharmacopoeia. A recent TV public service announcement on poison control in the home showed a housewife gathering drugs from the medicine cabinet and cleansers and other chemicals from under the kitchen sink and emptying them into the toilet bowl, to become part of the sewer wastewaters that would need to be dealt with in potable reuse systems. Chemicals are also part of our diet. "The Pill" and other steroids are not entirely eliminated in passage through the body. Commercial establishments also contribute a wide range of chemicals to the sewerage system.

Moreover, potable water reuse would only be an option in larger cities; in such cities a substantial level of industrial activity is expected. Even should the existing industrial enterprise be assessed and monitored, new industries using chemicals not yet invented can be expected. These will all be part of the input to a potable reuse system.

The second option, monitoring for these chemicals, and removing them by treatment suffers from precisely the same problems that face us today in dealing with the many water supplies drawn from polluted sources, such as those for New Orleans, Cincinnati, and Philadelphia. While it may be easier to monitor the discharges to a single sewerage system than over a large watershed, the risks are considerably greater because the concentrations of such chemicals are likely to be many-fold greater in wastewaters than in a river. Also, in a river there is time and distance between the sewer outfall and the waterworks intake processes that take place in a river. With direct potable reuse, an accident may well allow a slug of chemical to find its way into a water supply for distribution before being detected.

However, the major problem with potable reuse is in the establishment of levels of acceptance, or MCLs, for the various chemicals that may be considered to be important. The difficulty has been well demonstrated by the response of the National Academy of Sciences to the mandate of Congress and EPA with regard to the development of MCLs for individual chemicals. What is even far more difficult, in fact virtually impossible, is the establishment of MCLs for two or more contaminants that may be synergistic in their effects. The charge that had been given to the NAS in Section 1412, Par(e) (3) of the Safe Drinking Water Act is difficult enough when applied to those communities that are now being obliged to draw their potable supplies from polluted sources. Direct potable reuse would just add to this burden, exposing additional populations, including those who are more susceptible, and those who may be exposed to contaminants in other media other than drinking water.

Proponents of potable reuse (and despite their great number and articulateness, there is currently only one operating direct potable water reuse system in the world) often claim that the water they produce meets "Drinking Water Regulations". Thereby, they delude the public. First of all, regardless of the quality of the water produced from wastewater, that water cannot, by definition, meet the Drinking Water Regulations, because the regulations were never developed for a water supply drawn from wastewater directly. Furthermore, such a supply does not meet the stricture that it be from the purest source that is economically available.

More significantly, even if reclaimed water should meet the MCLs established in the current drinking water regulations, we know that such regulations are always many years behind our knowledge. The 1962 standards did not list any specific synthetic organic chemicals, so that a supply that might have contained many of them would have been satisfactory until 1976. The standards twenty years hence will be substantially different from the present standards, with many new chemicals added and the MCLs for some of the existing chemicals sharply reduced, such as has been suggested by the NAS for lead.(8)

Decisions made for large capital investments for intakes, treatment facilities, and transmissions mains, if based on water that can meet one set of MCLs and found to be unsatisfactory because the MCLs change, will not so easily be rectified. The decision of Cincinnati, to go to the Ohio River, rather than to groundwater, was made before anticipating the kinds of problems that would arise years later, and it is not so easy now to change the source of water or the method of treatment. On the other hand, cities that opted for protected upland sources or groundwater are not faced with these problems, as they will likely not be in violation of MCLs for chemical contaminants anytime in the future.

A program directed towards potable reuse encourages the public to believe that this is one of the options that would make preserving and developing protected water sources unnecessary. Many "environmentalists" have already proposed that potable water reuse take priority over the development of pure water supplies. A good case in point is the environmentalists' push in California for recharge of aquifers with reclaimed wastewaters as an alternative to developing additional protected water supplies. Not precisely in the same category, but reflecting similar attitudes, is the mandate by Congress to the Corps of Engineers to study the potential for taking water from the Potomac estuary for water supply for the metropolitan Washington, DC area, rather than developing upland reservoirs.(9) The concern for adding contaminants to an underground aquifer that cannot easily cleanse itself has led to a moratorium on wastewater recharge in California, pending the results of research investigations into the health significance of that approach.(10) The Corps is now studying the treatment of Potomac estuary water with a one-mgd pilot plant.

One of the problems with research into potable reuse is that the results would be of quite limited applicability. Potable reuse is warranted in relatively few locations. It may very well be that Denver is one of those places, but a successful demonstration in Denver, even if there were criteria on which to base success, would not likely lead to adoption in other places where there is little pressure and little need to move in this direction. A second problem lies in the fact that the technology for rendering a wastewater potable would be so sophisticated, and the monitoring required to assure safety so advanced, that few water purveyors in the US could afford to install and operate such systems.

"The Feasible Alternative"

The title of this symposium is quite clumsy and I must confess to being partially responsible for addition of the term "...And Feasible Alternatives". One feasible alternative to potable reuse, where water supply is short or supplies are of poor quality, is nonpotable reuse, or source substitution. EPA has in press Guidelines for Water Reuse which is intended for water purveyors and public officials.(11) An interesting facet of this manual is the large number of examples cited where communities have already initiated large scale programs of nonpotable reuse.

The most common nonpotable reuse systems are where wastewater is made available to one or two large users in the community. However, many systems have already been developed where essentially dual distribution systems have been provided and where the nonpotable reclaimed water is distributed extensively through the urban area for a wide range of uses, the most important of which are urban irrigation, recreation, and makeup for cooling towers. Some of these systems, such as the Irvine Ranch Water District, have been built without any federal funds. Others have used construction grant funds for part of the program.

What characterizes these programs is their success, as measured by the economies realized in funds and water, and their public acceptance, or even public pride. This could hardly be said of a program for potable water reuse. (One is reminded of the old saw "good news-bad news". The good news is that we will soon be drinking our own sewage; the bad news is that there won't be enough of it.) Nonpotable reuse satisfies a conservation ethic without any threat to the public health. The technology for treatment is simple. The treatment train that has been widely adopted is secondary effluent followed by coagulation and direct filtration and disinfection.(12) Considerable attention needs to be given to reliability, with effluent turbidity being the best marker for satisfactory performance. There need be no concern for removal of chemicals, and therefore no extensive monitoring for chemicals.

In addition to providing an opportunity for protecting the public from the longterm ingestion of waters containing synthetic organic chemicals, nonpotable water reuse has other benefits:

* Conservation of water - saving the higher quality sources for those services which require it;

* Recycling of nutrients that would otherwise need to be removed before discharge to receiving waters but that are beneficial when the water is used for urban and agricultural irrigation;

* Cost and energy savings that result from community water recycling;

* Reduction in the discharge of pollutants to water courses; and

* Realization of other priorities, such as the preservation of open space and the development of recreational areas.

One of the major problems with assisting in the development of potable reuse is the lack of integration of water supply and water pollution control programs at local and state levels and particularly in EPA. At the local and state levels, the fragmentation of the water supply and water pollution control industry results in the placing of outfalls above water intakes or the placing of water intakes below outfalls. Were there regionalization, somewhat on the style of the water suthorities created in England and Wales in 1974,(13) integrated planning for optimum utilization of water resources in a basin would be feasible, and more important, such planning could be implemented. In the case of Irvine Ranch Water District, the district has responsibility for distributing potable water, reclaimed water, and providing sewerage services. In most other instances, the fact that two separate agencies are involved leaves control of the reuse programs uncertain. Is it a water pollution control function or is it a water supply function? This has not been resolved in EPA.

The provisions of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) state that "...The discharge of pollutants into navigable waters be eliminated by 1984" and that the Administrator of EPA "...shall encourage waste treatment management which results in the construction of revenue producing facilities for ... the reclamation of wastewater..." Furthermore, the Clean Water Act of 1977 (PL 95-217) allows an additional 10% of construction grants funds for innovative and alternative approaches, and reuse of water is the first innovative approach mentioned. In addition, the President, in a Memorandum dated July 12, 1978, states that in the provision of loans and grants for municipal water supply and wastewater treatment systems, programs be modified "...to remove any disincentives to water conservation and to require appropriate community water conservation programs as a condition of such loans and grants." Clearly, nonpotable water reuse that substitutes for potable water supplies is an appropriate community conservation program.

Nevertheless, construction grants funds are denied or restricted when the projects are so-called "multipurpose", not directed to meeting an NPDES permit, even though the project provides for water reuse. One reason given for this posture is Federal fiscal constraints, that limited construction grants resources need to be reserved for pollution control measures. Thus the construction grant program for wastewater treatment constitutes a major disincentive for water conservation. Also, while the policy may conserve Federal funds, it wastes societal funds and resources. A community is deterred from implementing a water reuse program which may be the most economical water resources option because it is threatened with losing its construction grant for wastewater treatment. I do not happen to be a supporter of the construction grants program, discussion of which is beyond the scope of this paper. On the other hand, because construction grants are available, they inevitably guide the direction in which investments are made at the local level, and this direction is not towards nonpotable reuse even when it is clearly the most cost-effective option.

If nonpotable water reuse has a future, and it certainly does because it already has a very successful present, then the Federal government should at least get out of the way.

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"ISSUES IN THE DEVELOPMENT OF REUSE CRITERIA AND STANDARDS FROM A CONSULTANT/MUNICIPAL UTILITY VIEWPOINT"

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INTRODUCTION

I am pleased to participate in this EPA-sponsored symposium aimed at developing protocol for potable reuse criteria and standards and evaluating feasible alternatives. During the past 7 years a number of reuse seminars and symposiums have been conducted. We have discussed nearly every aspect of water reuse except criteria and standards. If we are serious in our reuse objectives, and we certainly should be, then it is long overdue that we begin to develop criteria and standards for all water reuses, i.e. agricultural, industrial, recreational, ground water recharge and potable. Since it is the primary objective of this symposium to discuss potable reuse, most of my comments will relate to that very limited aspect of water reuse.

In the past 7 years, we could probably cite a hundred reasons why we should not consider potable reuse in a country blessed with almost unlimited water resources. However, when addressing the long-range water resource requirements, only one reason is needed to begin looking at direct potable reuse - namely that no other viable alternative exists. When conservation has been programed to the maximum, when every conceivable industrial and agricultural reuse has been achieved, when dual distribution systems have been installed wherever applicable, when new sources of raw water have been explored, the only remaining option will be potable reuse. There is one exception - stopping all growth and directing where people can and cannot live and significantly changing lifestyles. Since this is not a viable option for us to consider today, I have not addressed the alternative any further. In parts of this country, direct potable reuse on a municipal basis will be required before the turn of the century. Yet, we are just now beginning to demonstrate the efficacy of the required treatment process. We have not begun to complete the health effects research necessary for indirect reuse, which is being practiced in hundreds of United States communities, let alone design and complete the health effects research program necessary for potable reuse. And before all of this occurs, we need to establish criteria and standards for the various categories of reuse.

Our reticence to deal effectively with our water reuse problems probably derives from our inability to recognize the very slight difference between indirect and direct reuse. The former is occurring daily at hundreds of locations, the latter will occur in the immediate future. We should no longer attempt to define a potable water by defining its source of supply. We have found there is no such thing as an "uncontaminated source," as the 1963 U.S. Public Health Service regulations were premised upon. The 1974 Safe

Drinking Water Act clearly addresses the problem of contaminated ground water and surface water supplies. Criteria and standards for potable water should not be based entirely on the source of supply. While the quality of the source must be considered, in both design and regulatory approaches, the criteria should be broad enough to relate to all water resource possibilities because all will be required for use in the future.

The state of the art of advanced wastewater treatment and potable water treatment is such now that good quality potable water can be produced from seawater, brackish water and municipal wastewater, if we are willing to pay the price of advanced water treatment processes and fail-safe technology.

Since it is the objective of this symposium to develop potable reuse criteria and standards, I will divide the remainder of my presentation into five parts:

Part 1. The Role of Potable Reuse in Meeting Municipal Water Needs

Part 2. The Necessity of Criteria and Standards for Municipal Planning and Consultant Design Purposes

Part 3. An Outline of the Specific Consultant/Municipal Utility Issues

Part 4. Evaluating the Role of Nonpotable Options in Meeting Urban Water Needs and the Need for Generally Applicable Criteria and Standards

Part 5. The Institutional Arrangements: Local, State and Federal

Part 1. Role of Potable Reuse in Meeting Municipal Water Needs

Over the next 20 years, it is not anticipated that potable reuse will play a major role in meeting municipal water demands nationally. This is primarily due to the many more cost-effective options available to the local utility. I am sure most, if not all, water utilities will make maximum use of nonpotable options before selecting potable reuse. As a result, potable reuse will continue to be very site specific. In my opinion, potable reuse will be selected when:

1. There is no other alternate source of supply available.

2. Potable reuse is less expensive than new raw water resource development.

3. Potable reuse provides a higher quality water than the present supply.

The United States Water Resources Council report of October 1977 projects freshwater use to decline from 338 BGD in 1976 to 306 BGD in the year 2000. At the same time, total consumption will increase from 107 BGD to 134 BGD between 1975 and 2000. Domestic and Commercial use will rise from 27 BGD to 35 BGD by the year 2000. It is interesting to note that the total domestic/commercial usage totals less than 9 percent of the 1975 freshwater offstream uses, and the report predicts domestic/commercial uses will be less than 12 percent by the year 2000.

Then why consider potable reuse at all? The answer is quite simple - communities like Denver, Phoenix, Los Angeles and hundreds of small towns have outgrown their conventional source of supply. People wish to continue to live in these communities and the price of water whether imported, when available, or recycled is not a significant economic factor. I believe that water reuse will continue to be very site specific, decided upon locally and paid for by revenues developed from the sale of the product. The major concern for the Federal and state governments should be "can it be done safely" 100 percent of the time and what criteria and standards are necessary to ensure the safety of the recycled water.

Part 2. The Necessity of Criteria and Standards for Municipal Planning and Consultant Design Purposes

Water resource planning at most water utilities covers a period of 15 to 20 years. It is a process of relating growth, projected demands and available supply to alternatives. To properly evaluate potable reuse as a possible alternative, the local water authority will need to know the costs associated with each alternative. Costs can only be derived when precise water quality standards and specific design criteria are known. It can be argued that these criteria and standards can only be established after the necessary health effects research has been done and the process reliability established by demonstration efforts. This leads one into a chicken or egg situation - which comes first?

The Denver reuse research is based upon current state of the art technology, with health effects research included as part of the demonstration program. There is no question in my mind that the efficacy and fail-safe technology of the treatment process will be demonstrated. Denver has also agreed to share the expense of the health effects research. The current estimated costs of this 1-mgd research program is now estimated to be in excess of $25 million of which the local utility will pay all but $7 million. I would suggest that we do not need to reinvent the wheel at each proposed reuse site. EPA, working with the state and local health departments, water utilities and consultants, should establish water quality standards for potable water reuse now. As more research and demonstration projects are undertaken and more information obtained, the standards and design criteria can be reevaluated and adjusted to comport with the new research and process control technology. The regulatory role should be the same as it is now under the 1974 Safe Drinking Water Act. EPA and the states accepting primacy of the Safe Drinking Water Act should establish standards and regulations for the final product. They should not, however, mandate the treatment processes. However, the regulatory agency should review and approve the proposed treatment train. (There is a difference.)

The criteria and standards should relate to the present state of the art technology gained over the last 100 years of treating all varieties of waters and wastewaters. The task will be formidable enough without making a supposition that a mystery Agent X - either virus, organic or inorganic - will cause the project to fail. Ways to fail will be easy to come upon - ways to succeed will test the skills and ingenuity of the entire water supply industry. Chemical and microbiological standards should be addressed as specific MCL's in the product water. Monitoring criteria will have to consider the source and quality of the "raw" water supply. I'm sure a degrade supply will require additional qualitative surveillance in both organic and inorganic compounds. Besides health effects criteria, standards must also relate to economics, process reliability, aesthetics and public acceptance.

Part 3. An Outine of the Specific Consultant/Municipal Utility Issues

I have been asked to outline the specific concerns or issues that a consultant and municipality might have with the potable reuse criteria and standards. I do not propose to speak for all consultants or all municipalities in this regard. Nor do I suggest that my list of issues is complete. Rather, I will attempt to define some of the more important issues and concerns.

Municipal

1. Standards, while relating primarily to health effects, must relate to economics and the real world alternatives.

2. To be of value in the planning process, standards for all types of reuse are needed now. They should not await the results of 5 or 10 years of research and demonstration projects.

3. Most agree that separate standards for potable reuse are acceptable. Eventually, however, water quality standards should relate to the final product and not to the various sources of supply. At the present time, there are at least five raw water categories which could result in at least five sets of water quality standards.

4. Municipal- and investor-owned utilities are concerned that any Federal or state standard not preempt their rights to evaluate local water resource options or treatment trains; specifically, that the regulatory body not preempt the local option.

5. EPA and state regulatory agencies begin now to conduct the health effects research necessary for both indirect and direct reuse. Since this research is part of the regulatory process, it should be funded nationally.

6. Research and demonstration projects be done now and not await a crisis condition in water resource planning.

Consultant

1. Design criteria should relate to both effluent quality and the quality of the source of supply.

2. Criteria and standards of wastewater reclamation facilities are necessary before developing the basic design.

3. EPA and state regulatory agencies should promulgate water quality standards and approve design. They should not mandate treatment process specifications. No single treatment process will be applicable to all wastewater reclamation sites.

4. Criteria and standards should relate to proven health concerns, safety, costs and state of the art technology.

5. All criteria and standards should be subject to review and modification, if shown to be necessary, on a short-term basis.

6. Standards should relate to construction materials and the chemical environment created in the treatment process.

7. "Fail-safe reliability" needs further definition.

8. Standards should relate to existing, local water quality values for potable water.

9. Post-treatment contamination due to corrosive water is a real concern.

10. Variations of water quality within the distribution system must be considered.

11. Standards and criteria should relate to existing monitoring capabilities, i.e. 24-hour monitoring of total organic carbon (TOC), bacteria, and viruses with alarm and shut-down potential.

12. Criteria and standards are needed now on all water reuse applications - agricultural, industrial, ground water recharge, recreational and potable.

Part 4. Evaluating the Role of Nonpotable Options in Meeting Urban Water Needs and the Need for Generally Applicable Criteria and Standards

The following list of nonpotable options will undoubtedly be employed before attempting potable reuse.

1. Exchange wastewaters for unpolluted water. Many communities divert their raw water for potable purpose above the urban community and discharge runoff and wastewaters downstream of the urban area. Wastewater which is composed of transbasin or foreign water can be exchanged for unpolluted water when it is available in the river flows. The above exchange is possible under the appropriations doctrine.

2. Exchange wastewater for agricultural water. This type of exchange relates to foreign or transbasin

waters, i.e. community X exchanges its wastewater for agricultural water rights which are diverted above the urban area.

3. Industrial Wastewater exchange. Waters owned by industry, i.e. nontributary ground water, can be exchanged downstream for water rights divertable at upstream water treatment plants.

4. Wastewater for industrial water. Industrial water demands that are presently satisfied from the potable water distribution system can be met by using high-quality wastewater. This option requires a second distribution system that may, or may not be cost effective.

5. Wastewater for parks, golf courses, parkways, etc. Those systems which presently supply their parks, golf courses and parkway with irrigation water from the potable distribution system can meet these demands by using wastewaters. It again requires a second distribution system.

6. Ground water recharge where geologic conditions and state water law permits.

7. Mandatory conservation programs.

Many of the above options are currently being used to increase the quantity of potable water available for domestic use. It again points up the need for establishing criteria and standards for industrial reuse, agricultural reuse, recreational reuse, ground water recharge, and potable reuse.

Part 5. The Institutional Arrangements: Local, State and Federal Roles

Since the passage of the Safe Drinking Water Act in 1974, EPA has had an opportunity to develop and establish institutional responsibility for administration of the Act. I believe at the present time 48 states have accepted primacy. The institutional arrangements necessary to administer water reuse between the Federal and state governments have also been established. The same arrangements have not been formalized with local health departments. And because potable water reuse is site specific, it will be necessary to work closely with county and local health departments. They should be a part of local decisionmaking processes on each type of water reuse.

If the concept of potable reuse is to be acceptable on a local level, public education and information agencies will need to be heavily involved and their activities coordinated. Within the Federal establishment, EPA will need to coordinate water reuse with the following agencies:

1. Department of Interior
    - a. Office of Water Research and Technology
    - b. Bureau of Land Management
    - c. Water and Power Resources Service
2. Department of Agriculture
3. Water Resources Council
4. Others

To assist in formalizing the necessary institutional arrangements, EPA will need to develop a new reuse policy statement to include the following types of reuse:

1. Potable reuse
2. Industrial reuse
3. Ground water recharge and reuse
4. Recreational reuse
5. Agricultural reuse

A division of water reuse should be established within EPA to coordinate institutional planning and administration of water reuse programs nationally.

SUMMARY

In summary, I would like to emphasize several key points:

1. Potable reuse criteria and standards are needed now. They must relate to health effects, process reliability, costs and public acceptance.
2. EPA should establish a section within the Office of Drinking Water to coordinate and administer all reuse activity with the agency.
3. EPA should request additional funding now to initiate health effects research relating to potable reuse.
4. Only through a coordinated national effort will potable reuse research gain the credence and provide the answers necessary for a fail-safe reuse technology.

rijksinstituut voor drinkwatervoorziening

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REUSE, SUGGESTIONS CONCERNING QUALITY REQUIREMENTS

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22a

1. Introduction

Intended reuse of waste water is not a new concept. It is recorded that irrigation of waste water was applied before Christ in Greece.
Sewage farming was practice in Germany in the sixteenth century in the United Kingdom it was practiced until the late 1800's. In the United States sewage farming was introduced in the 1870's (1). In case of unsatisfactory treatment the practice of irrigation presents risks as has been proven in my own country. Due to infiltration of sewage in the beginning of this century a neighbouring groundwatersupply is forced to apply active carbon filtration.

Several projects based on reuse of water for agricultural purposes have been reported at the end of last century. Especially in water short areas like Australia, India, Israel, several parts of the United States, South Africa and Rhodesia, irrigation with reclaimed water is popular (2) (3) (4) (5) (6).

Under pressure of an increasing demand for water in future caused by population growth and economical expansion many research projects and several plans on reuse of effluents have been set up in the sixtees and the beginning of the seventees, not only in arid areas but also in heavy populated areas, strongly industrialised areas and areas with very restricted water resources (2) (4) (5) (7) (8) (9) (10).
These plans concern aquifer recharge, irrigation for agricultural purposes and landscape watering, reuse in the recreational field, reuse in industry or reuse for potable supply. Several of them have been realized only partly at this moment.

Also enforced by strict regulations on discharges of effluents industry has nearly in silence turned to recycling of water. Municipal effluents are more and more used by groups of industries because of economical reasons.

Recharge with treated effluents of the aquifer is applied in practice at several

places in the world. Major existing projects of direct * reuse are the coastal barrier project in Orange County and the Dan Region project in the Tel-Aviv area.
Indirect * reuse to recharge the aquifer is practised in the Netherlands since the beginning of the fiftees. After treatment river Rhine water ($\gtrsim$ 10% sewage) is introduced into the dunes to replenish the groundwater extracted for drinking water production (175 x 10^6 m^3/year, 10% rainwater from origin) and as a barrier against the increased salt intrusion.

Reuse for recreational purposes is related with agriculture and landscape watering when it concerns the common practice of irrigating sportsfields and passive recreational areas. Also lagoons of treated effluents are used recreationally. The most famous example outside of the U.S.A. is probably the Baldeney Lake in the Ruhr area, Germany.

Direct reclamation for potable use was still a topic in the beginning of this decade. Apart from the Chanute case (Kansas 1952 - 1957) only the Windhoek reuse-project has been realised. Windhoek is situated in a very arid region. The available conventional supplies could not meet the water demand. Direct reuse has been the only solution. Some other reclamation plants (e.g. Cape Town) are expected in South Africa in the future (5).
The main reason of the stagnation in reclamation for potable reuse is the fact that growth in water demand is in general lower than expected. Another point is the great number of organic micropollutants discovered since 1970 in municipal waste water which can hardly be removed completely by advanced treatment.

Indirect reuse of effluents for potable supply is much more in use, often unwittingly. A great number of projects also belong to the category aquifer recharge such as Orange County, Dan project, dune infiltration in the Netherlands, Virgin Isles project and the Hong Kong plans (12).

Another category of indirect reuse is the production of drinking water from surface waters containing a considerable percentage of sewage effluent. Examples are the river water storage basin supplies in the Netherlands and

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*Direct reuse: The planned and deliberated use of treated waste water for some beneficial purposes as irrigation, recreation, industry, the recharge of underground aquifers and human consumption.

*Indirect reuse: Reuse when water already used one or more times for domestic or industrial purposes is discharged into fresh surface or underground waters and is used again (11)

Germany and several supplies in the United Kingdom. Also in the so-called "third world" countries this kind of reuse is practised frequently, sometimes causing calamities. The main streams are used for waste discharge and drinking water production and especially in the dry periods the percentage of effluents can be predominant.

2. Reuse of waste water for agricultural purposes

As the infiltration rates are generally low in most cases there are no special water quality requirements with regard to the technical aspects of the irrigation with waste water.
Sanitary requirements focus primarily on toxic effects on man and cattle staying in the irrigated area and/or consuming the crops and/or grass from this area. Secundary requiment can be based on the reduction of growth of crops by waste water constituents.

In 1973 the W.H.O. has published some criteria (13). These criteria are listed in table 1.

Table 1
WHO criteria on reuse for agricultural purposes

Crops eaten raw	100 coliforms/100 ml in 80 % of the samples No chemicals that lead to undesirable residues in crops.
Crops eaten cooked	Significant removal of parasite eggs, significant removal of bacteria. No chemicals that lead to undesirable residues in crops
Crops not direct for human consumption	Signicant removal of parasite eggs No chemicals that lead to undesirable residues in crops

In table 2 the criteria of the State California (14) are listed.

Table 2

CDO wastewater reclamation criteria for wastewater (State of Cal., 1973)

Reuse	Allowable coliforms (MPN/100 ml)
Food Crops	
Spray irrigation	2.2
Surface irrigation	
General	2.2.
Orchards and vineyards with no fruit contact with water or ground	not specified
Fodder, Fiber & Seed Crops	
Fodder, fiber and seed crops	not specified
Pasteur for milking animals	23

The policy of the South African department of Health is more restrictive. In general no irrigation with sewage effluent is allowed on crops that may be eaten raw. Surface irrigation of fruit trees, trellised vines and crops not eaten raw is allowed with effluent that has undergone at least tertiary treatment and contain less than 1000 E coli type bacteria/100 ml.
Similar requirements apply to irrigation of pastures for beef cattle although no grazing is permitted during irrigation. Dairy cattle may not at all graze on these pastures (5).

In 1975 the University of California has published a list with recommended Maximum Concentrations of trace elements (15).

This list is reproduced in table 3.

Table 3

RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATERS (UC COOPERATIVE EXTENSION 1975)

	Allowable Concentration (mg/l) (a)	
Constituent	For Waters Used Continuously on all Soil	For Use up to 20 Years on Fine Textured Soils of pH 6.0 TO 8.5
Aluminum (Al)	5.0	20.0
Arsenic (As)	0.10	2.0
Beryllium (Be)	0.10	0.5
Boron (B)	0.75	2.0
Cadmium (Cd)	0.01	0.05
Chromium (Cr)	0.10	1.0
Cobalt (Co)	0.05	5.0
Copper (Cu)	0.20	5.0
Fluoride (F)	1.0	15.0
Iron (Fe)	5.0	20.0
Lead (Pb)	5.0	10.0
Lithium (Li)	0.075 (b)	0.075 (b)
Manganese (Mn)	0.20	10.0
Molybdenum (Mo)	0.01	0.05 (c)
Nickel (Ni)	0.20	2.0
Selenium (Se)	0.02	0.02
Vanadium (V)	0.1	1.0
Zinc (Zn)	2.0	10.0

(a) These levels will normally not adversely affect plants or soils. No data is available for Mercury, Silver, Tin, Titanium, Tungsten.

(b) Recommended maximum concentration for irrigating citrus.

(c) For only acid fine-textured soils or acid soils with relatively high iron oxide contents.

In relation to the growth of crops the University of California formulates its cooperative extension guidelines for interpretation of quality of water for irrigation (15). These guidelines are listed in table 4.

Table 4

UC COOPERATIVE EXTENSION GUIDELINES FOR INTERPRETATION OF QUALITY OF WATER FOR IRRIGATION (a)

Problem and Related Constituent	No Problem	Increasing Problems	Severe
Salinity (b)			
EC of irrigation water, mho/cm	750	750-3000	3000
Permeability			
EC of irrigation water, mho/cm	500	500	2000
SAR (c)			
Specific ion toxicity (d)			
From root absorption			
Sodium (evaluate by SAR)	3	3 - 9	9
Chloride			
me/l	4	4 - 10	10
mg/l	142	142 - 355	355
Boron, mg/l	0.5	0.5 - 2.0	2.0 - 10
From foliar absorption (e) (sprinklers)			
Sodium			
me/l	3.0	3.0	--
mg/l	69	69	--
Chloride			
me/l	3.0	3.0	--
mg/l	106	106	
Miscellaneous (f)			
NH_4 - N,			
mg/l for sensitive crops	5	.05 - 30	30
NO_3 - N,			
HCO_3 (only with overhead sprinklers			
me/l	1.5	1.5 - 8.5	8.5
mg/l	90	90 - 520	520
pH	Normal range	6.5 - 8.4	--

(a) Interpretations are based on possible effects of constituents on crops and/or soils. Guidelines are flexible and should be modified when warranted by local experience or special conditions of crop, soil, and method of irrigation (UC Cooperative Extension, 1975).

(b) Assumes water for crop plus needed water for leaching requirement (LR) will be applied. Crops vary in tolerance to salinity. Refer to tables for crop tolerance and LR. The mmho/cmx640 = approximate total dissolved solids (TDS) in mg/l or ppm; mmho x 1,000 = microhos.

(c) SAR (sodium adsorption ratio) is calculated from a modified equation developed by U.S. Salinity Laboratory to include added effects of precipitation and dissolution of calcium in soils and related to CO_3+ HCO_3 concentrations.

(d) Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use salinity tolerance tables). For boron sensitivity, refer to boron tolerance tables.

(e) Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride absorption under low humidity/high evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads.)

(f) Excess N may effect production or quality of certain crops; e.g., sugar beets, citrus, avocados, appricots, etc. (1 mg/l NO_3 - N = 2.72 lbs.

In the framework of the European Convention for the protection of international watercourses against pollution limits with regard to water quality for agricultural purposes are proposed. These limits are bipartite. The first group of criteria concerning heavy metals and bacteriological aspects is formulated with regard to the health of the consumer of the crops. The second group of criteria exists of an overall picture of salt (chloride) tolerance (16).

These limits are reproduced in table 5 and 6

Table 5

Quality criteria for irrigation water in mg/l

European Convention

Recommended		Imperative	
Al	< 5	As	< 0.1
B	< 0.5	Be	< 0.1
Cr (VI)	< 0.1	Cd	< 0.01
Co	< 0.2	Hg	< 0.002
Cu	< 0.2	Mo	< 0.01
F	< 1	Se	< 0.02
Fe	< 2		
Pb	< 0.5	Feacal coliforms	
Li	< 2.5		< 10 / ml
Mn	< 0.5	at higher concentration irrigation should stop 14 days before harvest or consumption	
Ni	< 0.2		
Zn	< 0.1		

Table 6

Quality limits for the application of fresh water directly or indirectly to land for agricultural purposes.
European convention for the protection of international water courses against pollution

Limits relating to salinity beyond which yield reduction may start

	TDS * (Chloride - ion in mg/l)		
	Greenhouse	Open	
	600-1000 mm per year	Humid 100-300 mm per year	Arid 300-1000 mm per year
Very sensitive	160 (40)	500 (200)	250 (70)
Sensitive	400 (100)	1250	750 (200)
Moderate salt tolerance	800 (200)	2000	1000

From a bacteriological point of view the European limits are less stringent than the Californian requirements. For trace elements the requirements are in general at the same level. There is a remarkable difference in approach in relation to lead. With regard to growth reducing salt concentrations : in Europe these are supposed to be at a lower level.

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* Total dissolved solids

3. Reuse of waste water for recreational purposes

When waste water is irrigated on sportsfields and recreational areas the main risk for the recreant is a bacteriological infection. This will be also the case when recreating on or in lagoons or lakes receiving treated effluent. The Health Department of California has listed a number of criteria (14). These criteria are summarized in table 7.

Table 7

CDH Waste water reclamation criteria for waste water

Landscape irrigation	Coliforms MPN/100 ml
Golf courses	23
Cemetaries	
Freeway landscaping and landscaping	
Parks, playgrounds, schoolyards	2.2.
Recreational Impoundment	
Non restricted	2.2.
Restricted to non-bodily contact	2.2.
Landscape non-contact	23

In Australia the conditions for reuse for landscape watering and recreational irrigation are (2):

- BOD of the effluent should be $<$ 30 mg/l
- Effluent must be chlorinated,total coliforms below 1000 per 100 ml
- Effluent distribution system must be clearly identified
- Public should be excluded from areas being irrigated
- Grounds should not be used for sporting purposes until they have thoroughly dried.
- Samples of effluent should be submitted for bacteriological and chemical analysis

4. Reuse of waste water in industry

Recycling and reuse of sewage in industry play an important rôle. It gives a great number of factories widespread over the world that regain their polluted waste waters. It is beyond the scope of this lecture to go into details. Every type of industry has its own requirements. Nevertheless these special requirements have also an aspect in common, a basic quality from which at reasonable costs the required quality can be produced.

A number of cases in which groups of industries use the same (municipal) effluent is reported by Harlin [9). The most general example is the quality of the municipal effluent used by the San Francisco Bay group:

BOD	< 2 mg/l
Suspended solids	< 1 mg/l
Total Nitrogen	< 2 mg/l
Total Phosporus	< 0.2 mg/l

Based on the general requirements quality limits for surface waters used for the production of industrial water have been proposed by the Council of Europe in the framework of the European Convention for the protection of international water courses against pollution.

These limits could give a good starting point in the formulation of quality criteria for effluents to be used by industry. A selection of the limits is given in table 8.

Table 8

A selection from:

Quality limits for the production of water for industrial purposes
general requirements
European convention for the protection of international watercourses against pollution

BOD	8 mg/l
Cl^-	250 mg/l
SO_4^{2-}	150 mg/l
NH_4^+	2 mg/l
P (tot)	1 mg/l
Phenols	0.04 mg/l
$KMnO_4$-cons.	15 mg O_2/l
N (Kjeldahl)	3 mg/l
Detergents	0.5 mg/l
CCD	30 mg/l
Fe	2 mg/l
Ca + Mg	2 mmol/l

5. Reuse of waste water for aquifer recharge

Two different technical approaches are applied: infiltration and injection by wells. As to the first approach the infiltrate passes the so-called unsaturated zone. Many processes, possibly increasing waterquality, occur. As to the second approach the quality of the recharged water remains unchanged until mixing.
In practice the most important difference in the requirements lies in the bacteriological field.

Caused by the long duration and the high rates of infiltration and injection clogging in the soil as well as severe bottom and groundwater pollution will be the results if no precautions are taken. A solution against clogging can sometimes be found in intermittant infiltration. For the same reason infiltration water shall be kept low in suspended solids (< 5 mg/l), plankton($<$10-20 mg/l), bacteria ($<10^5$/ml) and the nutrient phosphorus ($<$50 µg/l).

Deterioration of the aquifer can only be prevented by using a high quality infiltrati or injection water. Strictly spoken in case of injection the effluent should have groundwater quality. In case of infiltration the purifying capacity of the unsaturate

In The Netherlands the first studies on aquifer recharge were carried out in the thirties. In the beginning of the fifties some projects have been realized. Quick filtrated River Rhine water was infiltrated by means of infiltration canals. Caused by the continuing decrease in quality of the river water (organic micropollutants, heavy metals) and because of technical reasons (clogging) pretreatment has been intensified. At the moment a complete coagulation process is applied. The salt content of river Rhine water (Cl^- 200 à 300 mg/l) has led the water supply of The Hague to turn to river Meuse water.

At present the seven dune water supplies together recharge about 160 x 10^6 m^3 yearly.

A new plan, possibly to be carried out in the future in the Veluwe area and based on an infiltration of at least 100 x 10^6 m^3 yearly is projected in such way that hardly any exchange between infiltrate and original ground water will occur. This approach safe-guards the quality of the original groundwater (17).

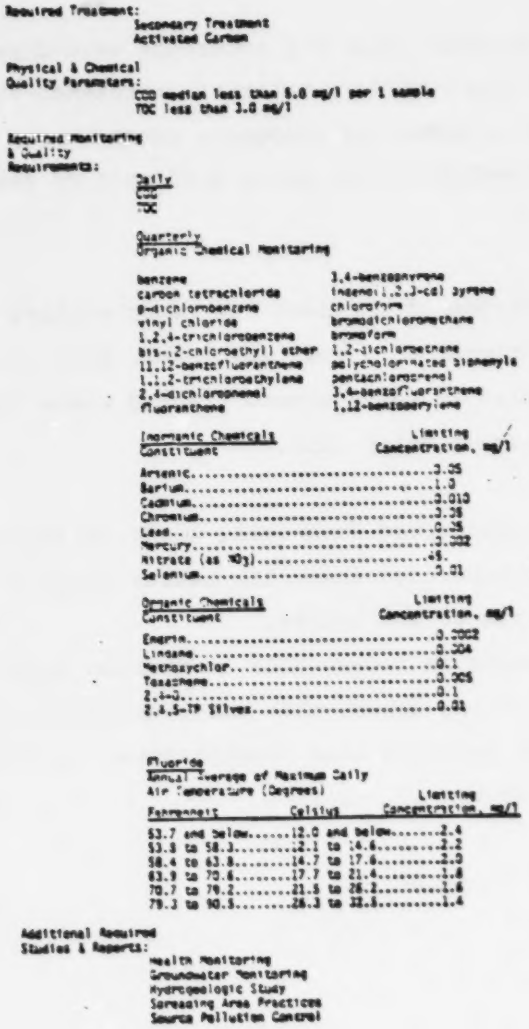
Other important recharge projects are the Dan Region project in Israel, 15 x 10^6 m^3 yearly and three projects in California namely the Orange County project against salt intrusion, at present only running water factory 21, but with a future capacity of 35 x 10^6 m^3/year, the San José Creek project (Los Angeles), capacity 16 x 10^6 m^3/year and the Whittier Narrows project (Los Angeles) capacity 9 x 10^6 m^3/year (18) (19).

A Californian proposal on the quality requirements of waste water to be reclaimed through groundwater recharge is reproduced in table 9.

Table 9

Summary of California regulation on wastewater reclamation through groundwater recharge (from Highlights pag. 75)

September 1977 version



Required Treatment:
Secondary Treatment
Activated Carbon

Physical & Chemical Quality Parameters:
COD median less than 5.0 mg/l per 1 sample
TOC less than 3.0 mg/l

Required Monitoring & Quality Requirements:

Daily
COD
TOC

Quarterly
Organic Chemical Monitoring

benzene
carbon tetrachloride
p-dichlorobenzene
vinyl chloride
1,2,4-trichlorobenzene
bis-(2-chloroethyl) ether
11,12-benzofluoranthene
1,1,2-trichloroethylene
2,4-dichlorophenol
fluoranthene
3,4-benzopyrene
indeno(1,2,3-cd) pyrene
chloroform
bromodichloromethane
bromoform
1,2-dichloroethane
polychlorinated biphenyls
pentachlorophenol
3,4-benzofluoranthene
1,12-benzoperylene

Inorganic Chemicals Constituent	Limiting Concentration, mg/l
Arsenic	0.05
Barium	1.0
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as NO_3)	45.
Selenium	0.01

Organic Chemicals Constituent	Limiting Concentration, mg/l
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP Silvex	0.01

Fluoride
Annual Average of Maximum Daily Air Temperature (Degrees)

Fahrenheit	Celsius	Limiting Concentration, mg/l
53.7 and below	12.0 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Additional Required Studies & Reports:
Health Monitoring
Groundwater Monitoring
Hydrogeologic Study
Spreading Area Practices
Source Pollution Control

6. Reclamation for potable reuse

Up till now direct reuse has been accepted only in a few cases of urgent needs. Indirect reuse for potable supply in which the effluent has lost its identy is accepted at several places.

When starting projects on potable reuse the interests were directed to inorganic parameters and to some for gross-organic material representative parameters like COD and BOD. With regard to a number of inorganic constituents like nitrate and in particular chloride and sodium it was quite difficult to meet an acceptable quality.

The advances in organic analyses of the last few years enabled measurements of organic micropollutants routinely at a very low level. Some hundreds of these compounds have been identified in waste water, treated waste water but also in river water and even in drinking water (20).

Many of these compounds are suspected from being toxic or carcinogenic, but in general there is an enormous gap in knowledge about the health risks of these compounds in relation to low concentrations or low intake.
Advanced treatment of effluents is indeed able to reclaim water quality in this respect but not far enough. Among others this has been proven by very recent results of our Dutch treatment plant applying lime precipitation, ozonisation and carbon filtration as described by Hrubec (7) (21).

These results are expressed in table 10.

Table 10

Analysis results of physical chemical treatment
(concentration in nanogram/litre)

Compound	Effluent	Before active carbon treatment	After active carbon treatment
Aromates			
benzene	300	100	100
toluene	100	100	100
ethylbenzene	30	30	10
styrene	30	10	10
m/p xylene	30	100	30
o-xylene	30	30	30
C_9H_{12}(alkylbenzene)	30	30	10
C_9H_{12}(alkylbenzene)	-	100	10
naphthalene	-	10	10
Organo-halogen compounds			
chloroform	1000	100	-
trichloorethene	100	100	-
bromoform	1000	1000	-
dibroomchloromethane	100	1000*	-
tetrachloroethene	3000	10	10
trichloropropane	100	30	-
dichlorobenzene	300	10	10
bis(2-chloroisopropyl)ether	100	100	-
trichlorobenzene	-	-	-
tri(2-chloroethyl)phosphate	3000	3000	10

Oxygen containing compounds

nitrobenzene	30	30	-
triethylphosphate	100	10	-
nitrotoluene	-	-	-
Σ benzaldehyde-2C (3 isomers)	300	30	100
1,1-diethoxy-2-phenylethane	100	30	<10
dimethylacetofenon(not confirmed)	100	-	-
triisobutylphosphate	300	<10	-
benzophenone	1000	-	-
tributylphosphate	300	100	10
dibutylphthalate	300	100	30
diisobutylphtalate	-	100	10

Nitrogen containing compounds

N,N-dimethylbenzylamine	100	-	-
N-ethylaniline (not confirmed)	30	10	10
methyl-quinoline	100	-	-
Di pyridile	100	30	-
N-n-butylbenzene sulfonamide	1000	300	100

Other compounds

cyclohexane	30	30	300
benzothiazole	100	30	10
di-isobutylthiophene (not confirmed)	300	<10	-
2 methylthiobenzothiazole	100	-	-

From this kind of results it could be concluded that quality requirements concerning a great number of organic micropollutants have to be formulated. However, such a conclusion is unpractible and an unacceptable simplification.

Making a comparison between the gaschromatograms of river Rhine water, used for direct and indirect (by artificial recharge) production of drinking water, and municipal waste water, raw material in the plant just described, the result will be a preference for municipal effluent especially with regard to halogenated compounds (fig. 1).

At the moment the Dutch watersupplies using river Rhine water as raw water source are not enforced to measure a great number of organic micropollutants. Only because of their sense of responsability these kind of surveys are carried out regularly.

A second complication is the nearly complete lack of information on the toxicological effects of the intake of very low amounts of organic micropollutants. Even for the environmentally very widespread group of halogenated aromatic compounds only a few standards exist as can be seen from table 11. Moreover these standards are mostly based on organoleptic properties only (22).

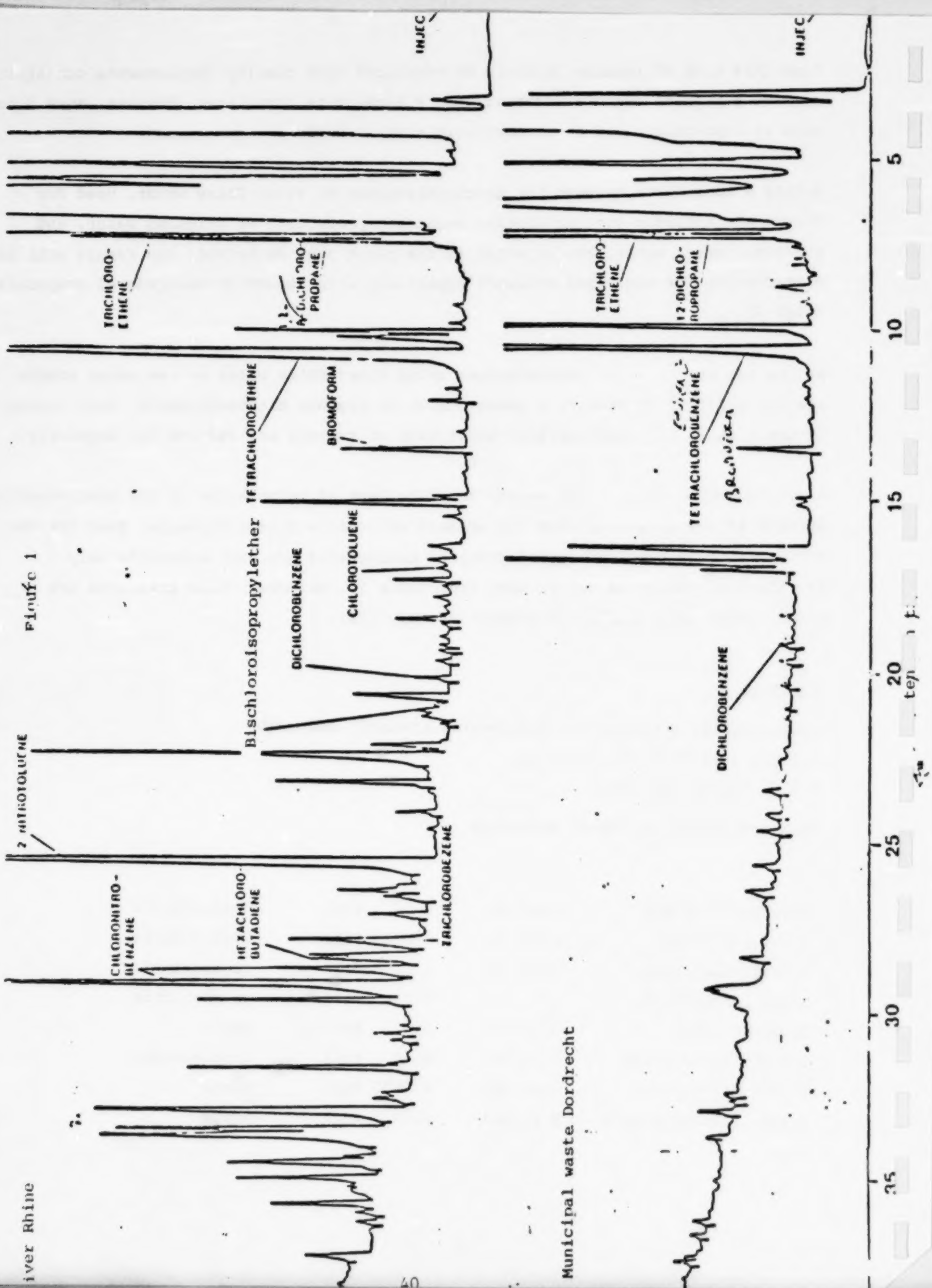
Table 11

Toxicological appraisal of halogenated aromatic compounds
following groundwater pollution
W.H.O. Copenhagen 1980

Existing (drinking) water standards

Monochlorobenzene	U.S.S.R.	0.02	mg/l	organoleptic
Dichlorobenzene	U.S.S.R.	0.002	mg/l	organoleptic
Trichlorobenzenes	U.S.S.R.	0.02	mg/l	organoleptic
Hexachlorobenzene		0.01	mg/l	as pesticide
Chloroaniline	U.S.S.R.	0.2	mg/l	toxic
3,4-Dichloroaniline	U.S.S.R.	0.05	mg/l	organoleptic
2,4-Dichlorophenol	U.S. EPA	0.0005	mg/l	taste
2,4,5-Trichlorophenol	U.S. EPA	0.01	mg/l	taste

Figure 1


River Rhine
INJEC
TRICHLORO-ETHENE
1,1-DICHLORO-PROPANE
TETRACHLOROETHENE
BROMOFORM
Bischloroisopropylether
DICHLOROBENZENE
CHLOROTOLUENE
2 NITROTOLUENE
TRICHLOROBENZENE
CHLORONITRO-BENZENE
HEXACHLORO-BUTADIENE
Municipal waste Dordrecht
INJEC
TRICHLORO-ETHENE
1,2-DICHLORO-PROPANE
TETRACHLOROBENZENE
Bromoform
DICHLOROBENZENE
5
10
15
20
25
30
35

In the W.H.O. drinking water standards (1971) only polycyclic aromatic hydrocarbons are included. In 1981 the standards will be replaced by new guidelines. A special task group will be installed to discuss the organic parameters. A small working group has selected the parameters to be taken into account in the task group. From table 12 it will be clear that the new W.H.O. guideline will only cover a small part of the immense problem of organic micropollutants in drinking water despite of the efforts to be as complete as possible.

Table 12

Selection of organic substances for inclusion in W.H.O. guidelines for drinking water quality (The Hague, 1980)

Parameters to be discussed by the organic task group

Carbon tetrachloride
Methylenechloride
1,1,1-trichloroethane
Dichloroethylenes
Trichloroethylene
Tetrachloroethylene

P.A.H.'s

D.D.T.
Aldrin and Dieldrin
Heptachlor
Chlordane
Lindane
Methoxychlor
BHC (α and β)
HCB
Triazine Herbicides
2:4 D

Monochlorobenzene
1,2-dichlorobenzene
1,4-dichlorobenzene
Trichlorobenzenes

2-chlorophenol
4-chlorophenol
2,4-dichlorophenol
2,4,5-trichlorophenol
2,4,6-trichlorophenol
Pentachlorophenol

Benzene
Toluene

Trihalomethanes (to be selected by the Task Group)

A special problem in relation to direct reuse is the persistance of viruses to desinfection processes. Viruses will be nearly always present in raw waste waters from large cities (24). Limits for viral contamination of raw effluents as well as finished drinking water are listed in table 13.

Table 13

Permissible limits viral contamination

Water intended for direct reuse as potable	< 1 in 100 - 1000 l
W.H.O. drinking water 1971	< 1 in 10 l
U.S.A. proposed drinking water	< 1 in 4000 l
U.S.A. proposed recreational water	< 1 in 40 l

Despite the fact that groundpassage will remove viruses at least partly in case of indirect reuse by replenishment of raw groundwater sources, attention has to be paid to the possible occurrence of viruses in recharge water.

7. Advices with regard to potable reuse

As drinking water, reused potable water has to meet the drinking water standards. The most recent standards, just accepted by the Council of Ministers, are the E.C. standards for water destined for human consumption. A selection from the 62 parameters is reproduced in table 14.

Table 14

Water for human consumption
E.C. june 1980

A selection from 62 parameters

	Guideline	Imperative
Conductivity	400 m^S/m	
Chloride	25 mg/1	
Sulfate	25 mg/1	250 mg/1
Calcium	100 mg/1	
Sodium	20 mg/1	175 (150-1987)mg/
Potassium	10 mg/1	12 mg/1
Evaporation residue		1500 mg/1
Nitrate	25 mg/1	50 mg/1
Ammonium	0.05 mg/1	0.5 mg/1
$KMnO_4$ cons.	2 mg O_2/1	5 mg O_2/1
Mineral oil		10 µg/1
Phenols		0.5 µg/1
Boron	1000 µg/1	
Detergents		200 µg/1
Chlorinated organic compounds non pesticides	1 µg/1	
Iron	50 µg/1	200 µg/1
Manganese	20 µg/1	50 µg/1
Phosphate (as P_1O_5)	400 µg/1	5000 µg/1
Fluoride		1500 - 700 µg/1

With regard to organic micropollutants also this directive contain only restricted information. Because of lack of knowledge other new concepts appearing elsewhere in the next years shall be very restricted also.

For drinking water produced from non polluted ground- or surfacewaters it will be probably enough to meet the standards.

Maintaining the principle that source observation is an important aspect and keeping in mind that reused water is of suspected origin it is advisable that apart from the requirement of meeting the drinking water standards, reused potable water will be frequently surveyed on organic micropollutants with preference by GC-MS method. As one of the possible hazards of organic micropollutants lies in the field of carcinogenicity or mutagenicity periodically appropriate tests shall be carried out too.

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SOCIAL ACCEPTANCE OF WATER REUSE

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SOCIAL ACCEPTANCE OF WATER REUSE

INTRODUCTION

Unlike the past, present urban water supply planning is a drastically different, challenging, and complex task. Today, other factors impinge upon the efficiency of water use and planning to meet future demand. Data on national aggregate water use have little relevance because urban water supply planning is a local phenomenon. It is at the local level where the range of factors that determine the efficiency of water supply production is of interest.

There are primarily six forces that influence urban water supply planning today. First, there are environmental constraints in the procurement of additional supply: new reservoir sites have become increasingly scarce, and groundwater resources are becoming inadequate to meet the demands of urban areas. Gilbert F. White recently noted the depletion of groundwater as one of the six most important water resource problems in the world, and particularly in the United States. A second set of problems that constrain urban water resource planning is the existence of new laws and regulations: Political, legal, and institutional problems of interbasin transfers have proliferated until it is nearly impossible to plan for a transfer of water from one basin to another. Third, the concern for environmental quality, which mushroomed during the 1970s, has added significantly and constrained the opportunities in urban water management. Water quality standards have been established by passage of the Federal Water Pollution Control Act

Amendments (1972), the Safe Drinking Water Act of 1974, and the Clean Water Act of 1977. Fourth, the costs of energy have intensified the severity of all other problems, for example, pumpage costs have increased at record rates resulting in substantial increases in water rates. Fifth, an additional factor in the increased costs of water resource development since the early 1970s is the cost of money, which this year has witnessed a record high prime interest rate of 20 percent. Finally, in some urban areas, especially those experiencing a growth in population, the demand for water continues to rise.

Traditionally, the planning process started by projecting the population served, estimating per-capita water use, and then simply multiplying one projection by the other to derive the future water use. Armed with an estimate of future water need, the problem was to identify adequate and available sources of supply, usually additional reservoirs and/or well fields. However, the problem today is not solely an inadequacy of supply; instead a wide range of factors have an influential and important role in the planning and management of our urban water resources.

Concurrent with changes in the planning process has been a shift in perspective, that is, to a broader range of alternatives. The traditional response to increasing demand for water has been the development of additional supply. Those alternatives, for example, that would modify demand have been generally ignored. Similarly, this reliance upon technologies to increase supply instead of policies designed toward modifying the schedule of demand has been evident in another water resource problem--flood control. White (1973:16) noted that

> For a long time it was out of the question for a planning officer to study any way of dealing with flood losses other than by constructing engineering works or by providing relief.

In planning for urban water, the challenge is to determine the optimum combination of all alternatives to balance the supply and demand. Not only are the alternatives that increase supply considered, but those options that modify the demand for water are also evaluated, such as water conservation and recycling renovated wastewater. Moreover, according to the U.S. Water Resources Council, Second National Assessment, the amount of withdrawals in the U.S. is expected to decline from 338 bgd in 1975 to 307 bgd by the year 2000--a 9 percent decline. Industrial water use is expected to decrease from 51.2 bgd in 1975 to 19.7 bgd by the year 2,000--a 62 percent decline.

Recycling already has had a significant effect in the reduction of industrial water use, and water use efficiencies are expected to exert an increasingly important role in projected water use. The national emphasis on water recycling and water conservation is already reflected in actual and projected water use.

Expert opinion has been engaged in the problems and possibilities involved in water reuse. There is a growing body of knowledge concerning engineering techniques, economic feasibility, and health and safety standards. And currently, it must be added, there is a wide range of stances as to both the scientific and practical viability of implementing such use.

Because public response contributes a crucial key which, in our democratic society, so often determines whether or not an environmental solution is to be implemented, no program using recycled waste water could be initiated without public acceptance. Therefore, it is of primary importance to actually identify rather than merely anticipate, the nature of the public response.

By indicating the elements upon which public reaction is consciously or unconsciously based, new information is needed to contribute substantially to both the "promotion of water use efficiency" by the urban reuse of water resources and to the "improvement of management effectiveness" in the field of water resources. For instance, as previous research has shown, the problem of public acceptance of recycled water is a multifaceted one which depends upon the capacity in which the water is used. Planners, public officials, and resource managers should thus be aware that the use of recycled water for industrial purposes poses less of a problem than does that for cooking or drinking. Research has also demonstrated that the amount of exposure to the idea of recycled water that an individual has had weighs decisively upon his feelings about drinking recycled water. Water research professionals would thus be wise to gain support for a water reuse program through the implementation of a vigorous educational campaign. The content of such programs would depend upon knowledge of the factors that influence public acceptance of reuse for potable purposes.

The question of the extent to which the public would accept renovated waste water for variable uses was the focus of numerous research efforts during the 1970s including seven major surveys. A review of the literature concludes that much has been learned, and that many of the earlier suspicions were not warranted.

Before I summarize the findings of past research on public/social acceptance, it is important to devise and comment on the nature of the research: to identify cautions to the findings of the past research.

SOCIAL ACCEPTANCE OF RENOVATED WASTE WATER

A study of what the general public thinks and feels about water reuse encounters formidable difficulties at its beginning. First, except in rare instances, people have had little or no experience with recycled water; both questions and answers must be hypothetical. The "if-then" nature of such data suggest they be approached with considerable caution. Second, psychological theory, previous research on water reuse, and the history of public response to fluoridation all strongly indicate that the possible reasons for how John Q. Public reacts to the idea of using recycled water are both numerous and diverse. Third, what is reuse? When seeking to measure public acceptance, what is the explicit concept that is being conveyed? Fourth, many past studies were poorly designed, e.g., they lacked a control population. Fifth, what is learned in one site is not necessarily applicable to other sites. However, in light of these difficulties, it is surprising that of the studies completed during the 70's, a pattern did emerge. There was a striking similarity in the findings.

A review of the literature of the 60's and early 70's demonstrates a widespread belief among public health officials that the public would not accept renovated waste water. All of the past surveys suggest that a significant segment of the public would be willing to drink renovated waste water, there is significant variation among them, variation which may reflect regional differences in consumer acceptance. Johnson's survey registered the highest rate of initial public acceptance with 77 percent of the respondents expressing a willingness to drink renovated waste water. Others report a lower rate, with 48 percent of the sample, although still a substantial group, ready to drink renovated water. In summary, about 50 percent will be willing to drink when initially faced with the concept.

It is important to emphasize that these data on the acceptance of potable water reflect a *minimal* level of acceptance, since all other uses of reclaimed waste water are more acceptable. That is, as anticipated, acceptance of the idea of renovated water depends in large part upon the particular use intended. Responses to eight possible uses presented to a sample of consumers displayed three levels of acceptance correlated with three levels of closeness to the self. Thus, when usage involved *incorporation* of the water--drinking or cooking--acceptance was at its lowest level, 48 to 51 percent. Acceptance increased to between 78 to 81 percent as one moved to the somewhat less intimate uses involving *body contact*--swimming, fishing, washing, and irrigation of food products. Finally, acceptance reached its highest level as usage of renovated waste water was perceived as most distant from the self--96 percent approved its use for irrigation of golf courses and 94 percent for industrial cooling. The salient question arises as to why are some opposed and others in favor of drinking renovated waste water? What are the factors that affect consumers *attitude* toward drinking renovated waste water?

Previous research suggests that the manner in which an individual responds to the notion of using renovated waste water appears to be related to his education, his knowledge of water renovation, and past experience, his definition of the situation vis-a-vis his present water supply, and his faith in the efficiency of science and technology. The most significant finding in several of the studies is the relationship of a person's attitude toward reuse and his formal education and knowledge of reuse. Generally, the more formal education a person has had, the higher the probability of his receptivity to using renovated waste water. The Johnson, the Athanasiou and Hanke, and other studies all found this to be statistically significant. For example, 7 out of 10 of the respondents with a grade school education or less disapproved of renovated waste water for drinking, whereas, better than 6 out of 10 with some college education approved of the idea (Baumann and Sims). Similarly, the Johnson study, Baumann and Sims, and the Ackerman survey all found a significant relationship between a respondent's knowledge concerning use of renovated waste water and his level of acceptance.

Even at a minimum, some knowledge concerning the concept of recycling renovated waste water appears to have significant influence on a respondent's attitude. Of those respondents who could recall having heard about the notion of recycling renovated waste water, 52 percent were in favor of drinking it; whereas only 24 percent of those who were unaware of the possibility would accept it as a source of drinking water. Also, better educated respondents expressed a greater faith in science and technology; and, this belief was related to greater acceptance of renovated waste water.

A person's sex appears to be weakly related to one's attitude toward renovated waste water: men are more willing than women to accept potable use. And, there were no significant differences according to income independent of education. Age of the respondent is generally related to acceptance of drinking recycled renovated waste water. The respondents fifty years old are more reluctant to drink renovated waste water than those under fifty. Among the group over 50 years, approximately 25 to 30 percent approved of the notion of drinking renovated water, but under 50 years of age, the proportion of acceptance is raised to nearly 50 percent; which may be more a result of education and income rather than age.

The relation between political party affiliation with a respondent's attitude toward renovated waste water proved unsuccessful. Likewise, in a study by Johnson, there was no relationship between a respondent's attitude toward local government with his attitude toward renovated waste water.

Another factor considered an important factor in the public acceptance of renovated waste water is cost: would an increase in the price of water via conventional sources result in greater public acceptance of a less costly renovated waste water alternative? In one survey, three groups were given the choice of accepting a traditional source of supply (a reservoir) over renovated waste water but at different prices. One group was told that to maintain a conventional source of water supply would cost 25 percent more as compared to utilizing renovated waste water; the second group was told that the price would be 50 percent greater; and, a third group was told that their average monthly bill would be increased 100 percent. The interviewer calculated the *actual increase in the respondent's water bill* and did not rely on his interpretation of the meaning of the percentage increase. A fourth group was merely given the choice of utilizing reservoir water or renovated waste water.

Changes in the price of water do not appear to affect significantly a respondent's willingness to adopt renovated waste water. Increases in the price of water *in order to maintain conventional sources* of supply did not have any statistically significant effect on public acceptance of renovated waste water. Regardless of the changes in price the vast majority were unwilling to *change* their attitude and accept renovated waste water. The penalty of price increase does not appear to be effective in creating public acceptance of renovated waste water. The lack of this relationship was also evident in the recent comprehensive study by Bruvold in California: He identified 3 important values that affect public acceptance: 1) environment;

2) public health; and 3) conservation. Cost was seldom mentioned, but here again we can not conclude it is unimportant, it is just less important.

Another thesis suggests that a respondent's attitude is greatly influenced by his perception of the quantity and/or quality of alternative sources. That is, the manner in which an individual perceives the quality and adequacy of his existing sources of water supply profoundly influences his attitudes toward renovated waste water. Johnson found that if an individual perceived the water he currently used as polluted, he was more willing to accept renovated waste water. The data concerning this question are inconclusive. On the one hand, we find some support for this thesis. Water managers, for example, whose source of water supply was ground water, a generally less-polluted source when compared to surface supplies, were more reluctant to consider renovated waste water as safe, potable water than were the managers whose source of supply was either a lake, impoundment, or river.

Yet, data from other studies suggest the absence of a relationship between consumer perception of the quality of the existing source of supply and acceptance of renovated waste water. Respondents were requested to rate their drinking water according to five criteria: (1) overall quality to drink; (2) visual, cloudy material; (3) taste; (4) color; and (5) odor. Although a respondent's evaluation of his water as a source of drinking water was related to whether or not he would purchase bottled water, no relationship existed between his assessment of the five characteristics of water quality and his attitude toward renovated waste water. But, there is some evidence that the perception of adequacy of supply may be related to consumer acceptance of reuse. That is, when people perceive the supply as inadequate to meet future demand, then they are more likely to accept renovated waste water for potable uses.

SUMMARY AND CONCLUSIONS

In summary, there appears to be a relationship between public response to renovated waste water and what may be termed cognitive characteristics of that public--knowledge and education; that is, the more knowledgeable a person is, the more likely he is to favor recycling renovated waste water, including potable water use. Second, there appears to be an absence of such a relationship with those variables labelled "psychological." In brief, what the public thinks and feels about using recycled renovated waste water appears to depend primarily upon what they know about it and their general educational level rather than on unconscious fears of contamination or general belief concerning nature, technology, aesthetics, authority, progress or density. More specifically, a summary of the research of the 70's has determined the following.

First, initial consumer acceptance of the concept of drinking renovated waste water is approximately 50 percent. Second, initial consumer acceptance of renovated waste water varies with the type of use: if the reused water involves ingestion, approximately 48-51 percent approve; if ingestion is not involved but there is bodily-contact with the reused water, then the level of acceptance increases to 78-81 percent; finally, the highest initial acceptance of renovated waste water is for uses that are most distant to self (non-bodily contact and non-ingestive uses) reaching 94-96 percent acceptance. Third, consumer acceptance increases with greater awareness and more information about the nature of the water supply, distribution and treatment system. Moreover, those individuals who are better educated, have higher incomes, and who also have greater confidence in science and technology are more in favor of the concept of renovated waste water for potable uses. Fourth, consumer perception of the adequacy of the existing water supply appears to play an important role: if the existing supply is perceived as inadequate, then the greater likelihood water reuse is accepted. Finally, other factors that were either unrelated or weakly related to consumer attitudes toward water reuse were age, political party affiliations, and attitude toward local government. Also, price was not an important determinant in modifying an individual's attitude toward renovated waste water. Nor, do there appear to be any major psychological barriers to public acceptance of drinking renovated waste water.

Many of the findings of the past research must be accepted with caution; the overriding caution is that most were attitudinal studies of hypothetical questions of water reuse. Might not the rationality of the layman when asked how he would respond _if_ he were to use renovated water collapse when confronted with the actuality of using it? The importance of this "reality-testing" is emphasized by Bruvold in his 1975 review of attitudinal studies on public perception of renovated waste water: ". . . the studies reviewed treat only hypothetical issues. Research on _actual usage_ is needed to interrelate attitudes, beliefs, and behavior in a realistic manner."

Nevertheless, based upon the findings of previous research, it appears that consumer acceptance is _not_ a formidable obstacle in planning for water reuse: the public will accept renovated waste water provided the proper information programs are designed and implemented. For example, as Bruvold (1979) has demonstrated, information programs in his study sites would focus on questions concerning health, water conservation, and the enhancement of environmental quality.

The most formidable obstacles lie more in the minds of public health officials, engineers, and planners, especially their perception of consumer acceptability. What is not needed at this time are more attitudinal surveys. Instead, research on consumer acceptance must be creatively designed to measure whether in fact people will behave as they indicated they would when interviewed. The recent Bruvold study (1979) is an exemplary effort addressing this need. Second, a salient and important practical question is what is the most cost-effective public information program on water reuse. For example, what information should be provided to the consumers, at what stage in the planning process, by whom, and by what means?

Finally, additional research on the professional and personal biases of public health officials, engineers, and planners would contribute greatly in planning for reuse. For example, public health officials, engineers and planners must consider seriously the options to the goal of zero-risk in water quality planning, and incorporate the consumer's risk preference into the decision-making process. What are the costs and benefits associated with variable levels of water quality? And, once determined, what level of risk will the public be willing to accept? Answers to these questions will require a more sophisticated input from the consumers into water supply and water quality planning than has been obtained in the past.

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NON-POTABLE AND OTHER ALTERNATIVES IN THE DECISION-MAKING PROCESS

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Presented at Symposium for Protocol
Development: Criteria and Standards for
Potable Reuse and Feasible Alternatives

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NON-POTABLE AND OTHER ALTERNATIVES IN THE DECISION-MAKING PROCESS

By

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Potable reuse of municipal wastewater, the primary subject of this workshop, is a much discussed, debated and often controversial water reuse alternative. The technical literature is filled with data, information and conjecture on key aspects of potable reuse such as treatment technology, public acceptance, legal and institutional barriers, health effects, financing and risk assessment. There is even considerable disagreement and confusion as to the definition of potable reuse. What exactly is potable reuse? Is it "direct" reuse or is it "indirect" reuse? What, in fact, is the difference between direct and indirect reuse? The term potable reuse often has a negative connotation and resistance to the concept may be found in federal, state and local government, in the technical community and in the general public. Unfortunately this negative reaction to potable reuse often carries over to other reuse alternatives that may be implemented sooner and may be more effective, reliable, and cost-effective. There are known instances where the reuse of municipal effluent for industrial process water has been rejected due to plant officials reluctance to have their employees work in an atmosphere that is perceived to be unaesthetic and possibly unhealthy. It is important therefore to clearly identify realistic alternatives to potable reuse.

In discussion of non-potable alternatives to potable reuse it is important to clearly define the terms that are used so often. For the purpose of this discussion the following definitions are used:

- Reuse - The term reuse is applied to planned beneficial applications of municipal wastewater.
- Recycling - The term recycling is applied to internal use of wastewaters prior to discharge or disposal. The term in this paper refers to industrial recycling.

To avoid the confusion inherent in the use of direct and indirect, these terms will not be used. Instead, reuse or recycling will be defined as taking place when the wastewater retains its general identity in the reuse or recycle application.

PROJECTIONS.

The circumstances that generally lead to serious consideration of potable water reuse usually include the availability and cost of alternative water supplies. Often the need to augment existing water supplies is a regional problem rather than a local one that affects only one municipality. In these circumstances, industrial process waters, cooling waters and even irrigation wastewaters, or return flows, may be considered in addition to municipal wastewaters, as reuse or recycle candidates to alleviate water quantity supply problems. The general use alternatives to which these wastewaters may be reapplied include irrigation, power generation, industrial process and cooling, commercial, energy conversion, mining, fish hatcheries, and domestic. To place the non-potable alternatives in perspective, data from a national analysis of reuse/recycle needs and potential sponsored by the Office of Water Research and Technology is presented in Table 1 below.

Table 1

REUSE/RECYCLE SUMMARY

	Quantity (bgd) 1975	 1985	 2000
Fresh Water Withdrawals	362.7	356.3	330.9
Wastewater Recycle	139.1	386.7	865.5
Wastewater Reuse	0.7	2.1	4.8

The data in this summary indicates that the total reuse/recycle quantity may be expected to increase from 139.7 bgd in 1975 to 870.3 bgd in the year 2000. The data also helps somewhat in placing municipal reuse in perspective on a national scale. The municipal reuse fraction in 1975 is one-half of one per cent of the total reuse/recycle quantity. This percentage share of the projected reuse/recycle market is expected to remain about the same even though the actual quantity could increase seven-fold. Table 2 presents a somewhat more detailed breakdown of the potential for industrial recycling and municipal reuse.

Table 2

REUSE/RECYCLE PROJECTIONS (bgd)

	1975	2000
Steam Electric	57	517.3
Manufacturing Industries	61	316.2
Mineral Industries	21	32.0
Municipal	0.7	4.8
	139.7	870.3

The data presented is based upon realistic evaluations of available wastewaters, future water needs, availability of other water sources, geographic and climatic factors, and conformance to national discharge standards. In many water-short areas it appears that industrial process and cooling recycling may provide an alternative to potable and non-potable municipal reuse, that could have a considerably greater impact on supplementing existing water supplies. Process and/or cooling water recycling may allow available high quality water supplies to be reserved for domestic purposes thereby reducing or eliminating the need for municipal reuse. Dominant functional uses, be geographic areas are shown in Figure 1.

ALTERNATIVES.

The summary data shown above indicates that municipal reuse will provide a relatively small percentage of the total reuse/recycle projects. However small, the percentage the total quantity projected approaches five billion gallons per day, a very significant amount of water. There will be many instances where extensive industrial recycling is not feasible and the locations of municipalities, the availability of ground and surface water supplies, the costs of wastewater treatment and disposal and other factors may combine to make municipal wastewater reuse a realistic option. Potable reuse is but one of many alternatives that may be considered as a viable alternative for supplementing municipal water supplies. Twelve major municipal wastewater reuse alternatives are listed in order of increasing sensitivity in Table 3 below.

Table 3

RANKING OF REUSE APPLICATIONS IN ORDER OF INCREASING SENSITIVITY

RANK	REUSE APPLICATION
1	Agricultural Irrigation - Forage Crops
2	Agricultural Irrigation - Truck Crops
3	Urban Irrigation - Landscape
4	Livestock and Wildlife Watering
5	Cooling, Once Through
6	Cooling, Recirculation
7	Industrial Process and Boiler
8	Fisheries
9	Recreation
10	Public Water Supply - Groundwater
11	Public Water Supply - Surface Water
12	Potable

Local circumstances could result in some reordering of the sensitivity ranking and possibly some degree of expansion or consolidation of the reuse applications. Generally, however, the listings indicate that there are many major non-potable alternatives for reuse of municipal wastewaters that may be considered and evaluated along with potable reuse.

There are many factors that must be considered in the reuse alternative decision-making process. Some of these factors are:

- Supply Availability
- Use Sector Demands
- Quality Requirements
- Treatment Complexity
- Quality Assurance
- System Costs
- Energy Requirements

- Public Acceptance

- Legal and Institutional Considererations

- Public Health

- Financing.

More often than not non-potable alternatives should prove to be more feasible than potable reuse. In many instances availability of low quality waters will permit the use of municipal wastewater for low sensitivity reuse applications. The lower sensitivity applications, shown in Table 3, will normally require a lesser quality water than potable reuse. This lower quality requirement will generally result in a simpler treatment system along with its associated lower capital and O&M costs and lower energy requirements. A potable reuse treatment system might typically consist of ten or more unit processes or unit operations such as primary sedimentation, a biological reactor, secondary sedimentation, chemical clarification. recarbonation, multi-media filtration, selective ion-exchange, breakpoint chlorination, carbon adsorption, reverse osmosis and disinfection along with ancillary operations such as recalcining and carbon regeneration. In contrast a non-potable irrigation alternative might only require two-stage aerated ponds, disinfection and the necessary distribution system. Typical systems are shown in Figures 2 and 3.

Non-potable options could also be expected to normally encounter less resistanc in the vital non-technological barriers to reuse such as public acceptance and legal and institutional problems. Recent studies have indicated that public acceptance of the potable reuse option has generally increased during the past few years; however, potable reuse is still generally the least desirable alternative to the public when other options are available. This attitude may change significantly when the general public is convinced that a safe quality potable water can be reliably supplied from domestic wastewaters. The legal liabilities of not providing the required water for the various reuse alternatives must also be considered in the decision-making process.

Finally, the most important and probably controversial factor in considering municipal reuse alternatives is public health. A major portion of this workshop is related to the public health impacts of the potable reuse option. A key purpose of the workshop is stated as being, "to provide guidance with respect to approaches, problems, solutions and needed research or investigations for establishing a pathway to protocol development for potable reuse criteria and standards...". Obviously there is some distance to go before potable reuse is widely implemented. Table 4 shows the approximate current status of municipal wastewater reuse in the United States. The totals indicate a low degree of implementation however, as noted previously, the total quantity can be reasonably expected to increase seven-fold in the next 20 years. If we consider potable reuse as generally including "pipe-to-pipe" reuse, aquifer recharge, domestic surface storage and blending, it can be seen that the non-potable alternatives appear to be taking precedence even today.

There is no doubt that interest in potable reuse is increasing rapidly. The pioneering efforts by the Orange County Water District at Water Factory 21, the City of Denver Water Department, the South African water research community at Windhoek, and the efforts of the EPA Health Effects and Municipal Environmental Research Laboratories and others are providing major impetus for solutions and answers to major problems and questions. These efforts are undoubtedly advancing the state-of-the-art and the time when criteria and standards can be established and applied with confidence. Even then, however, potable reuse will remain but one alternative to be considered in the reuse decision-making process.

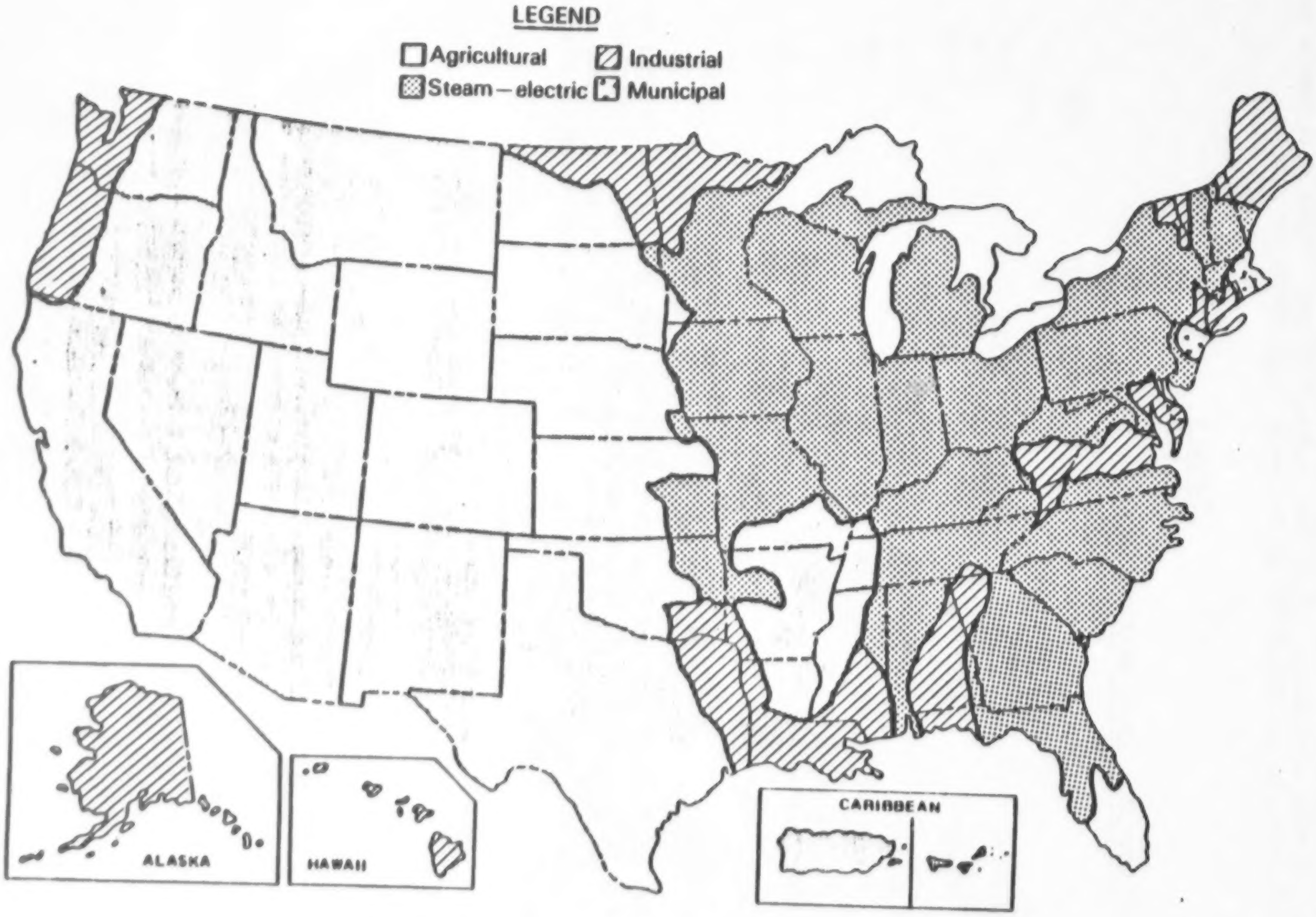
Table 4

EXISTING MUNICIPAL REUSE PROJECTS

	No. of Projects		MGD	
Irrigation	470		420	
Agriculture		(150)		(199)
Landscape		(60)		(33)
Not Defined		(260)		(188)
Industrial	29		215	
Process				(66)
Cooling				(142)
Boiler Feed				(7)
Groundwater Recharge	11		34	
Other (Recreation, etc.)	26		10	
	536		679	

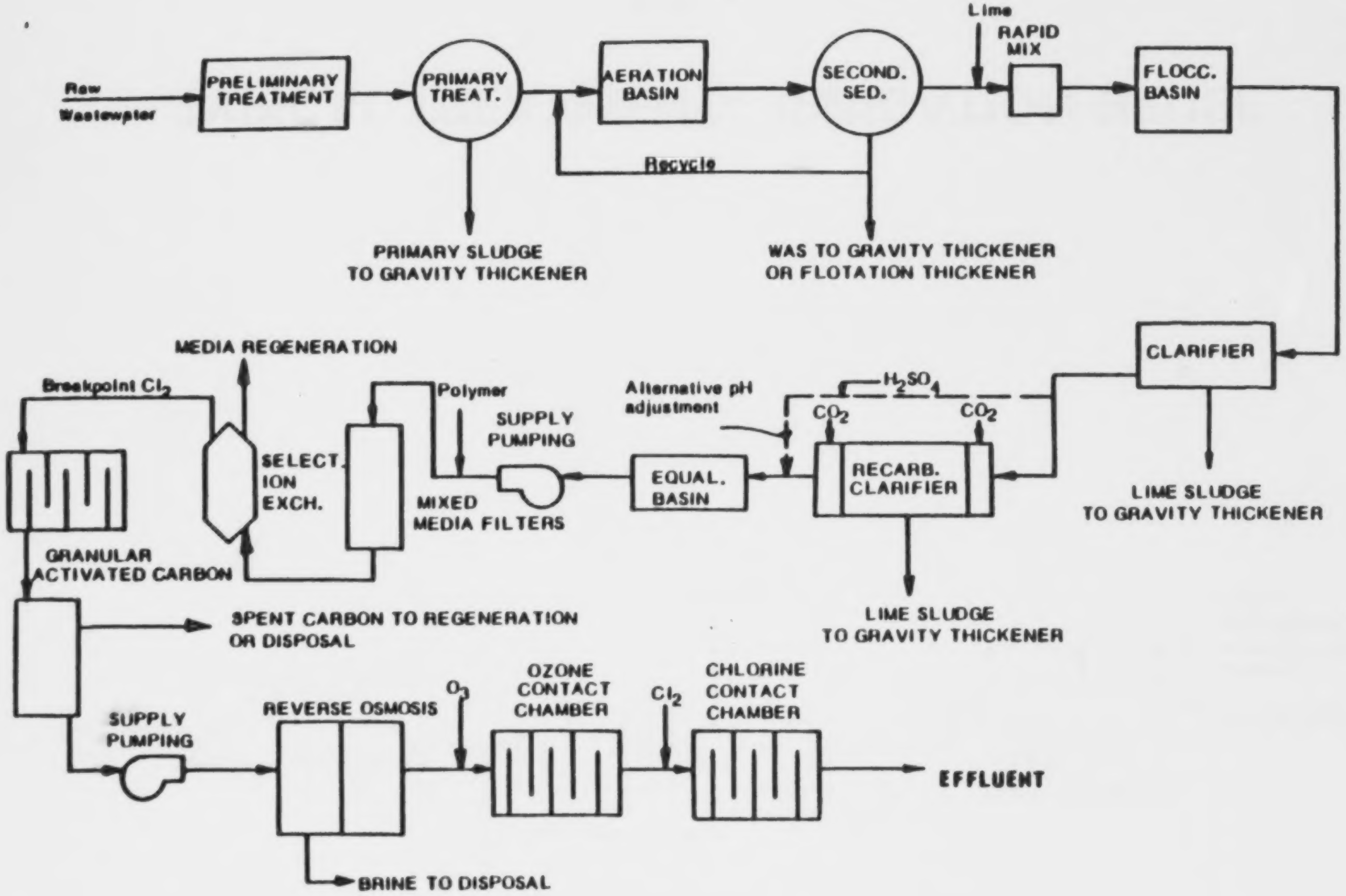
ACKNOWLEDGEMENT.

Much of the data used in this discussion has been abstracted from two OWRT sponsored reports prepared by Culp-Wesner/Culp of El Dorado Hills, California. These reports are: "Water Reuse and Recycling, Volume 1, Evaluation of Needs and Potential" (OWRT RU-79/2) and "Water Reuse and Recycling, Volume 2, Evaluation of Treatment Technology" (OWRT RU-79/1.



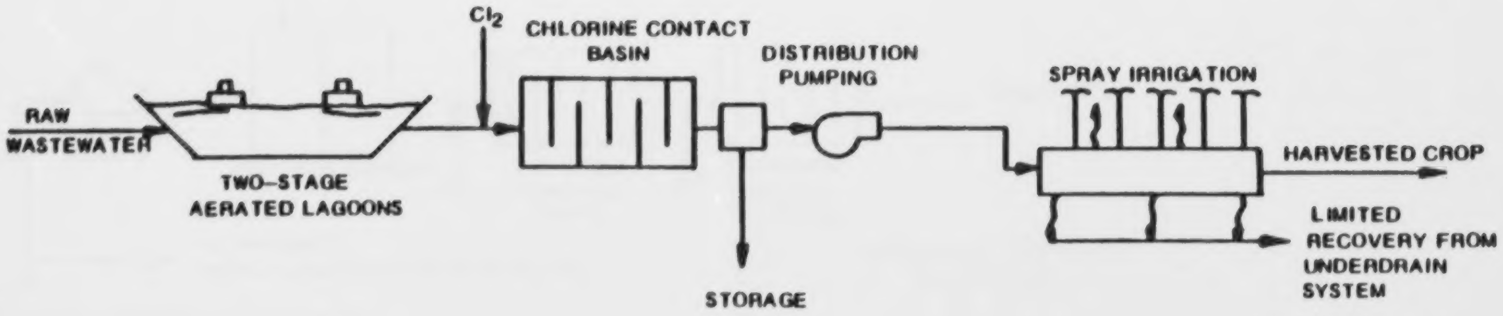
DOMINANT FUNCTIONAL WATER USES

FIGURE [illegible]



HIGHEST TREATMENT LEVEL—POTABLE REUSE

FIGURE 2



TYPICAL TREATMENT—IRRIGATION REUSE

FIGURE 3

WORK GROUP
REPORTS

Work Group Reports

Overview

Prior to the meeting an issues paper was prepared for each work group area to be used as a basis for focusing the discussions and potential findings and recommendations. The normal mode of issues paper preparation was by the chairman with varying degrees of review and assistance from others. However, a significant exception, the Chemistry Work Group chose to have extensive participation from several of its discussants in order to prepare technical background documents which are included as appendices. Utilizing these appendices and other available information the chairman prepared the issues paper.

During the afternoon of the meeting's first day the participants formed into six work groups, each addressing a specific technical/scientific area. The work group deliberations continued into that evening and through the next day with a plenary session for reporting back on the morning of the third day. The means of conducting and reporting back the results of each work group's deliberations were a little different. The groups and the form of their reporting are as follow:

Toxicology: Revised issues paper presented as the final report.

Chemistry: Combined report/issues paper with extensive detailed appendices.

Microbiology: Revised issues paper presented as the final report.

Engineering: Has both a final report and revised issues paper.

Ground-Water Recharge: Revised issues paper presented as the final report.

Non-Potable Options: Has both a final report and revised issues paper.

Prior to each work group's presentation, the chairman, reporter, discussants, resource persons and participants are listed.

Work Group Report

Toxicology

Chairman: Robert A. Neal
Vanderbilt University

Reporter: Jitendra Saxena
Office of Drinking Water

Discussants: Richard Bull
Environmental Protection Agency

Frederick C. Kopfler
Environmental Protection Agency

Michael Slimak
Environmental Protection Agency

Gedahliah Shelef
Massachusetts Institute of Technology

John Wilkins, III
Ohio State University

Participants: Raymond Anderson
Division of Water Supplies, Baltimore, Maryland

James Clise
Conference of State Sanitary Engineers

Thomas Klaseus
Minnesota Department of Health

Vernon J. Laurie
Environmental Protection Agency

Charles R. Malone
National Academy of Sciences

James Prieur
Argonne National Laboratory

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Conduct of Workshop

The work group was responsible for defining the technical options and issues with respect to developing criteria and standards for potable reuse and for recommending toxicological procedures for assessing health risks associated with planned and unplanned reuse of water. The technical expertise represented at the workshop included in vivo and in vitro toxicology, epidemiology, water/wastewater chemistry, sanitary/public health engineering, and microbiology.

The approach adopted by the work group for developing toxicological testing protocol involved the following three steps: (i) the Toxicology Work Group Chairman prepared "a straw man" for presentation to the toxicology work group. Specific areas addressed in the proposal included chemical contaminants of concern, biological endpoints, test material, and limitations of the proposed methodology including difficulties in extrapolation of data to humans; (ii) each aspect of the proposal was critically evaluated at the workshop and appropriate modifications in the proposal were recommended; and (iii) the proposal was further evaluated by the chemistry work group with respect to the feasibility of providing a representative concentrate of organics in reuse water requested in the toxicology proposal. The revised issue paper evolving from the discussions is presented here as the workshop report.

Dr. Gedahliah Shelef, a public health engineer in the work group, expressed the feeling that the recommended approach for assessment of risk associated with potable reuse was extremely expensive and time consuming, and proposed an alternative approach. In Dr. Shelef's opinion, direct potable reuse water should not have a special criteria but should comply with the most rigorous drinking water standards. Further details of his proposed approach are included as an appendix.

TOXICOLOGY HEALTH EFFECTS

DETAILED REPORT

INTRODUCTION AND BACKGROUND

The purpose of this document is to define those toxicological procedures which may be performed to evaluate whether a significant health risk is posed by consumption of water derived from planned or unplanned reuse. It is apparent that the most important question which arises in potable reuse of water is whether there is any significant health risk attributable to consumption of this water because of its content of bacteria, viruses or chemicals. It follows from this that the final deciding factors concerning the nature of the treatment train and the monitoring that must be done to assure the quality of the potable reuse water will be the results of the toxicological, microbiological and chemical evaluation of the finished reuse water.

The chemicals present in potable reuse water may be classified into four general types: organic chemicals, inorganic chemicals, suspended particulates and radiochemicals. The suspended particulate which is of greatest health concern is asbestos. It is clear that inhalation of asbestos leads to adverse health effects in man including lung disease and the induction of pulmonary cancer. However it is not clear at this time whether ingested asbestos poses a significant adverse health risk (1). Of those inorganic anions and cations which can potentially be present in finished water, those of greatest health concern are sodium, arsenic, barium cadmium, chromium, lead, mercury, silver, selenium, fluoride, nitrate, copper, iron, manganese, sulfate and zinc. Other inorganic anions and cations of some health concern may be periodically detected in drinking water. However, those listed above, because of their biological properties and frequency of occurrence in finished drinking water, pose the most significant adverse health risk to man. The potential adverse health risk posed by asbestos, inorganic chemicals and radiochemicals can be best controlled by monitoring at periodic intervals for the levels of these materials in finished drinking water.

The evaluation of the potential adverse health risk posed by organic chemicals in drinking water is a much more complex task. Recent monitoring surveys by the Environmental Protection Agency and others have detected in excess of a thousand different organic chemicals in finished drinking water supplies in the United States. Some of these chemicals are known or suspected to be carcinogenic but, with the exception of the trihalomethanes, trichloroethylene and tetrachloroethylene, these known or suspected carcinogenic. chemicals are either detected in drinking water infrequently or in very low concentrations.

The total organic carbon concentrations in drinking water may range from slightly less than a milligram per liter to as high as several milligrams per liter in water from surface sources. However, most supplies would fall in the range of 1-3 milligrams per liter.

Some of the compounds present in finished drinking water which pose a potential adverse health risk are present as a result of use of chlorine as a disinfectant. A number of other toxic and potentially toxic compounds are present in some drinking waters as a result of industrial pollution of source waters.

The majority of the organic material present in drinking water comes from natural sources such as decayed vegetation and consists of a highly complex mixture of compounds of which the fulvic and humic acids are the most important in a quantitative sense. The fulvic and humic acids are complex, highly substituted aromatic compounds whose range of structures has not yet been completely determined.

In considering the special case of drinking water obtained by direct reuse as compared to indirect reuse, of additional concern in direct reuse is the recycling and potential concentration of compounds such as industrial pollutants, drugs, halogenated organic compounds formed as a result of use of chlorine as a disinfectant, nitrogen compounds such as ammonia and nitrates which accumulate in reuse water because of their high content of organic waste and inorganic chemicals.

Although the current interest and the majority of the resources of regulatory agencies have been devoted to evaluating for the presence of carcinogenic and mutagenic chemicals in drinking water it is essential to recognize that chemicals present in drinking water may also produce acute effects, adverse effects on various organ systems including the hematopoietic and nervous system, effects on the immune system, teratogenic effects and effects on reproduction. Consequently any protocol for evaluation of potential adverse health effects of chemicals present in finished drinking water from potable reuse must take into account all the potential adverse health effects which may be posed by organic and inorganic chemicals, suspended particulates and radiochemicals present in finished drinking water.

It should be apparent that an important consideration in the indirect or direct reuse of water would be the control of industrial discharge into the source waters. If it is not possible to prohibit the discharge of industrial chemicals into the source waters, a complete knowledge of the chemicals that may potentially be discharged is essential. This would include intermediates used in the synthesis of industrial products themselves. Also, an estimate of the amount of discharge of these chemicals would be necessary. In the event there would be significant discharge of a chemical concerning which the toxicity to experimental animals and potentially to man is not known, the generation of data relative to the toxic potential of that chemical is essential. In addition to knowing the potential industrial pollutants that may be present in the source waters, a knowledge of the chemicals used for agricultural and household purposes in that region including a knowledge of the degree of contamination of the reuse water resulting from these household and agricultural practices is necessary in planning toxicological studies of the potential adverse health effects of chemicals present in potable reuse water.

TOXICOLOGICAL EVALUATION OF POTABLE REUSE WATER

As noted in the previous section it must be assumed that exposure to organic and inorganic chemicals, particulate matter and radiochemicals present in drinking water derived from planned or unplanned potable reuse _may_ cause a wide variety of toxic effects in man. Therefore, the appropriate tests or monitoring systems must be planned to anticipate and to examine for these toxic effects. Qualitatively the types of adverse health effects that might be anticipated are effects on organ systems including the hematopoietic and nervous systems, effects on reproduction, teratogenesis, induction of neoplasia, mutagenesis, and impairment of the competence of the immune system.

In the evaluation of potable reuse water for these various adverse health effects it must be recognized that geographic differences in the nature of potentially toxic chemicals in the finished drinking water may exist. These differences can occur because of different industrial, agricultural and household practices, and geographic variation in the type and amount of vegetation, the decay products of which may end up as organic contaminants in the drinking water.

Thus, in any evaluation of potential health risk from chemicals present in drinking water the first step is the determination, to the degree possible, of the chemical compositon of the finished drinking water including inorganic, organic, particulate and radiochemical contaminants. The potential for adverse health effects in man from those compounds with an adequate toxicological data base can be determined and maximum concentration limits (MCL's) set. For those compounds for which there is an incomplete data base, the use of suggested no adverse response levels (SNARLS) should be contemplated as an interim measure. Knowledge of the types and amounts of industrial discharge and contamination of the source water by agricultural runoff and household products is essential to the analytical evaluation of compounds in the finished drinking water which may pose a potential adverse health risk.

The second step in the evaluation of the potential for organic contaminants of the finished drinking water to pose an adverse health risk is the oral administration to experimental animals of a representative concentrate of the organic chemicals present in the finished drinking water. The major reasons for recommending the oral administration of the organic concentrate is that the separation, identification and toxicological evaluation of each of the organic compounds that will be present in a finished drinking water poses an impossible task. In addition, consumers of the drinking water will be exposed to the mixture of organic compounds and not to individual compounds. Therefore exposure of experimental animals to the mixture of organic compounds is the toxicologically sound approach. The exposure of the experimental animals to the mixture of organic compounds will take into account the possible antagonistic, additive and synergistic effects of the various compounds present in the finished drinking water.

The question arises whether each water supply that derives its drinking water from planned or unplanned reuse should subject their water supply to the extensive and expensive battery of tests suggested in this document. Since so little is known of the potential adverse health effects of simultaneous exposure to the myriad of organic compounds present in drinking water it is prudent that representative water supplies in different geographic areas with varying potential for contamination from industrial, agricultural and household practices and varying amounts and kinds of decay products from vegetation, be tested through this battery of tests for potential adverse health effects. As a data base is established concerning the potential for the combination of organic compounds present in these various drinking waters from different geographic areas to cause adverse health effects in man, then the determination of the extent of testing which each water supply using contaminated source waters must undergo to ensure the absence of significant risk can be better assessed.

The question also arises whether the methodology used to assess the potential toxicity of organic and inorganic contaminants present in finished drinking water should be different for water obtainable from planned or unplanned, direct or indirect reuse. Although the concentrations of toxic inorganic and organic contaminants may be different in planned direct reuse as compared, for example, to unplanned, indirect reuse the potential for adverse health effects only differs in degree and it is recommended that the same toxicological evaluation be carried out in each of these situations.

Of course an important development in carrying out the evaluation of the potential toxicity of the organic concentrate from finished drinking water is the ability of the chemists to provide to the toxicologists a representative concentrate of the organics present in finished drinking water. For the majority of the suggested toxicological studies to be carried out it would be sufficient to have a water solution or suspension containing a representative portion of the organic compounds present in the finished water at a concentration which will allow the daily administration to experimental animals of 1000 times the amount of these organic chemicals present in the finished water. These include the studies of acute, subchronic, teratogenic, reproductive, immunosuppressive, neurotoxic and all chronic effects except cancer. It is also possible that the required information concerning cancer could be obtained with this same concentrate. That is, if a significant increase in cancer were produced in animals exposed to 1000 times the normal concentration of the organic chemicals present in the finished water then the information necessary to quantitate the risk to man from exposure to the mixture of organic chemicals present in the finished drinking water would have been provided by the chronic rodent bioassay. However, if a significant increase in cancer were not produced by the 1000 fold concentrate in the usual number of animals exposed in a cancer bioassay (50 males and 50 females at each dose level) the assay may not be of sufficient sensitivity to ensure the absence of significant risks of cancer to humans exposed to the organic chemical mixture present in the finished water. It is possible that exposure of the animals to 1000 times the concentration of the organic chemicals present in the finished water, or some lesser concentration, would be the maximum tolerated dose in the chronic study. Therefore, it would be inappropriate, if excess mortality were expected, to administer a more concentrated solution of the organic chemical mixture to the animals.

The estimated maximum tolerated dose to be used in the chronic study will be determined in the subchronic (90-day) studies in rats and mice. If the results of the subchronic study indicate a maximum tolerated dose of greater than a 1000 fold concentration could be administered to the rats and mice in the chronic study, then it would be important for the chemists to attempt to provide the toxicologists with the maximum feasible concentrate of the organic chemicals present in the drinking water which is still representative of the organic chemicals present in the finished water. Once the chemists have determined the maximum degree to which the organic chemicals can be concentrated and still be representative of those originally present in the finished drinking water, and the toxicologists have determined the probable maximum tolerated dose of the mixture of organic chemicals present in the finished water, the number of animals under test for chronic toxicity (including cancer) can be adjusted to achieve the desired degree of sensitivity for the cancer endpoint. However, the maximum tolerated dose, as judged by excess mortality from causes other than cancer during the 24 months of the study, should not be exceeded merely to attempt to establish a dose at which cancer may develop. In this case, the excess mortality would itself be the most important toxicity endpoint. It is important that the inorganic chemical concentration in the organic concentrate not exceed that which would produce adverse osmotic effects in the rats and mice because of total concentration or toxic effects because of the concentrations of toxic inorganic components which may be present.

In the remainder of this section the suggested methodology for evaluating various potential toxic effects of organic, inorganic and radiological chemicals and particulate matter present in finished drinking water will be discussed.

Acute Toxic Effects

Inorganic Chemicals. The potential for acute toxicity in man from exposure to inorganic chemicals in finished drinking water derived from planned or unplanned potable reuse can largely be prevented by monitoring for inorganic ions known or suspected to produce toxic effects in man. The technology for monitoring for inorganic chemicals at levels that may pose a potential health risk are readily available (i.e., the atomic absorption spectrometry). In general the contribution of water to the total intake of toxic inorganic subtances is relatively low. However in some instances the concentration of inorganic chemicals in drinking water may reach levels which pose an adverse health risk. In those cases where the levels in water approach the limit where adverse health effects may be anticipated an evaluation of the intake of that inorganic compound from sources in addition to water should be considered. Maximum concentration limits (MCL's) have been set for the majority of those organic chemicals which produce toxic effects in man. The MCL's together with the appropriate monitoring should provide the means of assuring that inorganic chemicals do not pose an unreasonable acute toxicity risk to man from consumption of the finished drinking water. It is possible that a toxic inorganic chemical may be introduced into a particular source of water intended for reuse which is not normally monitored for. This can be largely prevented by being aware of the potential for industrial, agricultural or household contamination of the water source with this toxic inorganic chemical. If the possibility exists for contamination of the source water with a toxic inorganic chemical which is not normally monitored for, a system for examining for the presence of this inorganic chemical should be instituted.

Radiochemicals. The presence of radiochemical hazards associated with finished drinking water derived from planned or unplanned potable reuse can be assured by monitoring for radioactivity of various types (alpha, beta, and gamma) and enforcing the maximum radiological emission limits in finished drinking water which have been recommended for these various kinds of radiation. Also a knowledge of the potential for contamination of the source water with radiochemicals as a result of their use in industry, research or medical diagnosis is important.

Particulate Matter. The suspended material in water which potentially poses a health risk on ingestion by man is asbestos. However, ingestion of asbestos is not known to pose an acute health risk.

Organic Chemicals. To measure the potential acute toxic effects of organic chemicals present in potable water from planned or unplanned reuse will require a combination of monitoring for known acutely toxic organic chemicals which may reasonably be present as contaminants in the finished drinking water plus the testing in experimental animals of concentrates of organics from finished drinking water. The acute oral toxicity of the organics present in finished drinking water should be examined in young adult male and female rats,administering by gavage or gelatin capsule a representative concentrate of the organic compounds from the finished drinking water. It is recommended that the concentrate of organics administered be 1000 times the concentration found in the drinking water. If mortality is produced at this dose then lesser concentrations should be examined to establish the LD50. If no mortality is experienced at the 1000 fold concentration in either the males or females then no further testing for acute toxicity is recommended. The volume of the dosing solution should not exceed 4 to 5 milliliters per animal/day. This is equivalent to an intake of approximately 4-15 milligrams total organic carbon/animal/day assuming TOC of the reuse water in the range of 1-3 mg/ml. After dosing the animal should be observed for at least 14 days or until all signs of reversible toxicity subside whichever occurs later. At the end of the observation period all animals should be sacrificed and a complete gross necropsy should be conducted. All test animals dying during the test should also be subjected to gross necropsy. Additional details for measuring acute toxicity in rodents are given in references 2-5.

Subchronic Effects

Inorganic, Particulate and Radiochemical Compounds. As with acute toxic effects, the subchronic effects of inorganic and radiochemicals are best controlled by setting maximum concentration limits (MCL's). Again, as in the case of acute toxicity, the subacute toxicity of orally administered asbestos has not been demonstrated.

Organic Chemicals. Extremely useful information relative to the potential toxic effects of the combination of organic chemicals present in finished drinking water from planned reuse will be derived from subchronic testing in experimental animals. Results of this test will give valuable information about the ability of the combination of organic chemicals to produce adverse effects on various organ systems including the hematopoietic system, the nervous system and the immune system an on mortality. The test is usually conducted in two species; one test in a rodent species and another in a non-rodent species. The usual non-rodent species used is the dog. However, the difficulty in obtaining sufficient amounts of organic concentrate precludes the use of dog. Therefore, it is recommended that two rodent species be used in the subchronic study. The test should be carried out using equal number of males and females of each species. Three concurrent control groups (two negative and one positive) and one test group are recommended in these experiments. Three control groups are recommended. These are: (i) a group administered the organics concentrated from a ground water source not known to be susceptible to contamination from industrial, agricultural or household practice; (ii) a positive control group which will be administered an organic concentrate from a municipal water supply considered to be particularly vulnerable to industrial and agricultural contamination; and (iii) an organic concentrate from a municipal water supply prior to reuse (city of reuse). The test group should be administered an organic concentrate of the municipal water supply of the city practicing reuse or from pilot plants in case of cities planning reuse.

In these studies is is recommended that the organic concentrate from the planned reuse supply, the ground water supply and the municipal water supplies be administered in the drinking water. At least three dose levels should be administered and the studies be carried out for 90 dyas. If possible the highest dose level should result in some toxicological or pharmacological effects but not result in more than 10 percent fatalities during the progress of the test. In any event a level of organics 1000 times that in the finished water should be the upper dose limit. Ideally the lowest dose level should not produce any evidence of toxicity. If the animals do not tolerate the administration of the organic concentrate in the drinking water, it should be administered daily by gavage or contained in a gelatin capsule. All toxicological and pharmacological signs should be recorded daily including time of onset, intensity and duration. Such signs should include, but not be limited to, mortality, cardiovascular, respiratory, behavioral and central nervous system effects. Clinical parameters should be evaluated at the end of the subchronic tests. The clinical parameters should include hematology, blood chemistry, urine analysis and other tests that my be indicated by the symptoms which the animals may display. All animals in this study should be subjected to gross necropsy and to histopathological examination. Additional details concerning the conduct of subchronic studies are given in references 2 and 3.

It is recommended that a subchronic neurotoxicity study also be carried out using the organics concentrated from the finished drinking water from planned or unplanned reuse. Although neurotoxicity is an effect which is examined in the subchronic study described above, the laboratory rat and mouse are sometimes not the most sensitive animal species to use in examining for neurotoxicity. A more sensitive strain is often the domesticated chicken. In this study adult chickens of both sexes should be exposed to 3 dose levels of the organic concentrates from the reuse supply. The highest dose level should, preferably, be one which induces some toxic effects. However an intake of organics should not exceed 1000 times that present in the finished water. Ideally, the lowest dose level should be one which does not induce any deleterious effects. The control groups should be the same as described above for the conventional subchronic study. The organic concentrate should be administered in the drinking water if possible. Otherwise it should be administered by gavage or by way of a gelatin capsule. The length of the test should be 90 days or longer. Throughout the test period each animal should be observed daily and estimates of food consumption and body weight should be recorded periodically. The animals should also be examined for behavioral abnormality, local motor ataxia and paralysis. Moribund animals should be sacrificed to lessen the likelihood of unobserved death and subsequent autolysis. At the end of the experiment all test and control animals should be subject to gross necropsy. In addition, a histopathological examination should be performed on all test and control animals. Of particular importance is the histological examination of longitudinal and cross sections of the spinal cord in the cervical, thoracic and lumbosacral regions and ganglia; of the medulla and pons, cerebral and cerebellar cortex, basal ganglia and hippocampus; of the optic and other cranial nerves; and of the proximal,middle and distal peripheral nerves including the siatic nerve. Additional details for conduct of subchronic neurotoxicty studies are given in references 2, 6 and 7.

Chronic Health Effects

Inorganic, Particulate and Radiochemical Compounds.

The data concerning the effects of chronic ingestion of asbestos fibers on incidence of tumors is conflicting and incomplete (1). Consequently, it is not known at this time whether chronic ingestion of asbestos leads to an increased incidence of tumors in either experimental animals or man. However, because asbestos does produce cancer in man on inhalation it is prudent to keep the level of asbestos fiber in water to the lowest practicable level.

The potential adverse health effect from chronic exposure to inorganic chemicals and radiochemicals present in finished drinking water from direct or indirect reuse can best be estimated and controlled by monitoring for the levels of inorganic chemicals and radiochemicals in finished drinking water which are known to have adverse health effects in man and enforcing the MCL's or radioemission limits.

Organic Chemicals. The major emphasis of the agency relative to chronic effect of organic chemicals and more specifically synthetic organic chemicals present in drinking water has been the potential for these compounds to produce an increased incidence of neoplasia in man. However, it must be kept in mind that other chronic effects can occur on exposure to organic chemicals and the studies designed to examine for chronic health effects should consider all effects that may occur on exposure of man to organic chemicals present in drinking water. These include organ system effects, teratogenicity, neurotoxicity, adverse effects on reproductive system, effects on the hematopoietic and immune systems as well as an increased incidence of neoplasia.

The chronic toxicity test using the organic concentrates from the finished drinking water from planned reuse should be carried out in two rodent species, the laboratory rat and the laboratory mouse, or, perhaps, the hamster. If there is difficulty in producing sufficient amounts of the concentrated organic chemical mixture, the use of two strains of mice should be considered. Equal numbers of males and females of each species or strain examined should be used. The control groups should be those described in the subchronic study. The animals should be administered the concentrated mixture of organic chemicals on a daily basis for approximately 24 months or the normal life span of the strain used. At least three dose levels of the concentrated organic chemical mixture should be tested. The highest dose level should preferably be one which demonstrates some toxicological-pharmacological effects or, in the absence of biological effects, the highest representative concentration of the organic chemical mixture which the chemists are capable of preparing. However, this dose should be selected so as to not cause mortality in excess of 50% in the progress of the experiment. The subchronic tests can be used to predict what doses should be administered in this chronic experiment. The lowest dose level should be one which, ideally, does not produce any evidence of toxicity. The organic concentrates should be administered in the drinking water, if possible. Otherwise, the organic concentrate should be administered by gavage on a daily basis. Clinical laboratory testing should be conducted periodically throughout the experiment carrying out hematology, blood chemistry and urine analysis and any other test which is indicated by the symptomology shown by the animals. An interim sacrifice for gross and histopathology should be planned at the end of one year. Therefore enough animals should be started on the test to provide sufficient numbers of animals for this interim sacrifice. Dead or dying animals should be subject to gross necropsy and histopathology. At the termination of the experiments all animals should be subjected to gross necropsy and histopathological examination for organ system effects and for increased incidence of neoplasia. Observation of the animals for behavioral anomalies should also be included as part of this experiment. Additional details for conduct of chronic rodent studies are given in references 2, 3, 8 and 9.

Teratogenicity Studies. The organic concentrate from the finished drinking water from planned reuse should be examined for teratogenicity using the normal teratogenic tests in rodents. These studies should be conducted in at least two mammalian species. The preferred species are the rat, mouse, hamster or rabbit. The test should be carried out in young mature pregnant females of uniform age, size and parity. The control groups in these studies should be those described in the subchronic study. A positive control group is also required, in other words a group to which a known teratogen is administered. In these studies the organic concentrates should be administered daily in the drinking water or, if this is not possible, by gavage or in a gelatin capsule beginning at or before the time of implantation and continuing through the period of major organogenesis. Exposure of each species should encompass the gestation period up to one day before term. The fetuses should be delivered by caesarian section approximately one day before term and examined for reproductive anomalies. The study should be carried out with at least three dosage levels of the organic concentrate. The highest dosage level should, preferably, be one which induces some fetal or maternal toxicity as demonstrated by body weight reduction or other toxic signs but not cause more than 10% maternal fatalities. However, a dose in which the organic chemicals represent a 1000 fold higher daily intake than that in the finished drinking water need not be exceeded. The lowest dose level should, ideally, be one in which no toxic or adverse effects are seen. Additional details for the conduct of teratogenicity studies are given in references 2, 8, 10-12.

The Reproduction Studies. The potential for adverse health effects on the rodent male and female reproductive system of the mixture of organic compounds from the finished drinking water from planned reuse should be assessed. This can be accomplished using the standard two generation reproductive test administering the organic concentrate from the finished drinking water at the maximum tolerated dose and fractions of the tolerated dose. Again the control groups should be as described in the subchronic study. The mammalian species most commonly used in reproductive studies is the laboratory rat. At least three dose levels should be administered. The highest dose level should, preferably, produce an observable toxicological-pharmacological effect in the test animals but not cause more than 10% fatalities. A dose representing a 1000 fold increase in the daily intake of the organic chemicals in the finished drinking water need not be exceeded. The lowest dose level should, ideally, produce no observed adverse effects. The organic concentrates should be administered in the drinking water if the animal will tolerate it. Otherwise they should be given by gavage. The concentrates should be administered to two generations of animals. A third generation of animals should be exposed to the concentrates in utero and throughout nursing. In these studies observation should be conducted of the general condition and behavior of the mothers including nesting and nursing. The males should be examined for normal spermatogenis and histopathological examination of the testes should be carried out. All litters should be examined as soon as possible after delivery. Important observations are litter size, number of stillborn, number of live births, viability counts and pup weights at birth. In addition the pup weights at weaning should be examined. A complete gross necropsy and histopathological examination should be carried out on males and females of the F_1 generation and the control group. A complete gross necropsy and histopathological examination of randomly selected weanlings from each sex from each test group in each generation should also be carried out. Additional details for conduct of reproductive studies are given in references 2, 8, 13 and 14.

Mutagenicity/Carcinogencity Studies. Since the chronic study in experimental animals using organic conentrates from drinking water will be expensive, preliminary examination of these concentrates for mutagenic and mammalian cell transforming properties should be carried out using available "short-term" tests which have been shown to be reasonably predictive of the potential carcinogenicity of compounds based on their previous evaluation in the rodent bioassay. It is recommended that the battery of short-term tests should include a bacterial point mutation test such as an enhanced Ames assay with appropriate dose response, a point mutation test in a mammalian cell line such as those which have been developed using hamster embryo or mouse lymphoma cells, an *in vitro* transformation test using a mammalian cell line, an *in vivo* cytogenetic test and an assay for germ cell mutation (for example, a dominant lethal test). Additional details for conducting these studies are given in references 2, 13, 15-17.

Consideration should also be given to the use of some in vivo tests in rodent species currently under investigation by EPA. These include the initation-promotion of papilomas on Sencar mouse skin, the induction of enzyme altered foci in rat liver and the use of the Strain A mouse and examination for induction of adenomas of the lung on exposure of these animals, in vivo, to organic concentrates from finished drinking water. The battery of in vivo tests should be considered as a part of the preliminary screen of organic concentrates from drinking water for cell transforming and mutagenic properties. Using these batteries of "short-term" tests one could manipulate the treatment techniques so as to obtain a product water, the organic concentrate from which had reduced or negative results for mutagenicity cell transformation or preneoplastic changes in cellular biochemistry or morphology. However, in the final analysis the results obtained from the battery of short-term tests in regard to mutagenicity and potential carcinogenicity will have to be verified in the standard rodent bioassay using the same organic concentrates from finished drinking water which had been examined in these "short-term" tests. If the results of the battery of "short-term" tests are verified in chronic rodent bioassays using the organic concentrates from a few representative drinking water supplies (vulnerable, non-vulnerable, heavy organic contamination from vegetation, etc.) it is recommended, because of the cost of the rodent bioassay, to substitute the battery of "short-term" tests for the rodent bioassay for cancer.

Immune System Test. It is also recommended that tests examining the responsiveness of the immune system to the chronic administration of the organic concentrates from the finished drinking water from planned reuse and the various controls noted in the subchronic study be carried out. The experimental animals and controls on the chronic test described previously can be used for this purpose if sufficient animals are started at the beginning of the chronic test. The tests of immune competence to be applied are those used in standard practice.

Epidemiology

Epidemiologic studies are an important part of any assessment of the potential for adverse health effects from planned reuse drinking water. In the context of water reuse, and considering the "before and after" nature of planned reuse programs in particular, one appropriate and feasible epidemiologic strategy would be time trend analyses of age-, race-, sex-, and community-specific morbidity and mortal ity rates. For the most part, existing sources of morbidity and mortality statistics could be used to examine the frequency of morbid events in communities before and after the start of a reuse plan. If significant time trends are observed it must be determined if such temporal changes are artifactual, due to possible errors in the numerators and/or denominators of rates, or real changes in the illness patterns of the particular community or communities. Trend analysis could be performed for both acute and delayed effects and on an inter- and intra-community basis. If inter-community comparisons are to be made, control communities should be carefully matched on relevant demographic, socio-economic, and environmental characteristics. If adequate matching cannot be achieved, multivariate statistical techniques are available to control for those differences between communities deemed important. It may be useful to rely on formal time series analysis to discriminate random from real fluctuations in rates.

In the more general case of drinking water and health, particularly in the context of long-term low-dose exposures, there are still many unresolved issues. A major problem not satisfactorily dealt with in past studies (the majority of which have been aggregate population studies) is how to measure human exposures to drinking water contaminants in epidemiologic studies. In considering the nature of drinking water exposure variables, several questions arise. Is the variable qualitative or quantitative in nature? Is it a dichotomous or continuous variable? Are the exposure data cross-sectional or historical with respect to time? Does the variable reflect the exposure of individual subjects or the exposure of aggregate populations? Future epidemiologic studies of drinking water must improve the sensitivity of the methods used to investigate what are generally assumed to be relatively modest effects. Epidemiologic models and underlying biostatistical techniques must be particularly concerned with the statistical power of a test to detect real effects.

A sampling of other problems that have not been satisfactorily dealt with include long latent periods, population migration, and misclassification effects.

Because of the potential impact on public health, it will be important to monitor consuming populations for adverse health effects. Many sources of morbidity and mortality statistics are currently available for this purpose and should be exploited to the greatest extent possible. Although it may seem desirable to develop comprehensive disease reporting systems (e.g., cancer registries), an observed increase in some adverse response after initiation of a planned reuse program may be a result of improved case-finding alone. Since a system like a cancer registry is expensive to maintain, consideration should be given to conducting periodic population surveys as an alternative.

An epidemiologic monitoring program targeted at delayed effects possesses at least two disadvantages. Recognition of an adverse response in a human population may have been preceded in time, perhaps many years, by changes in quality such that the responsible agent or agents no longer pose a risk. Also, ethical problems come to light when long-term vigilance leaves large numbers of individual exposed to potentially hazardous substances over a long period of time.

Finally, although epidemiology is complicated by its observational nature, epidemiology and toxicology should be viewed as complementary disciplines. Toxicologic and epidemiologi evidence should be integrated together wherever possible during the process of making policy decisions.

Continuous Monitoring.

Although continuous monitoring for the occurence of potential carcinogens in the drinking water may be possible using short-term tests which are currently available or under development, similar relatively inexpensive tests for compounds producing reproductive toxicity, teratogenicity and/or organ system damage are not currently available. Therefore the best procedure to follow in regard to continuous monitoring for the introduction of new chemicals into the water supply that may have adverse health effects, is the analytical monitoring of the water supply and a continuous evaluation for industrial, agricultural and household discharge into the source waters of new compounds that may have potential adverse health effects.

LIMITATIONS IN ASSESSMENT OF POTENTIAL ADVERSE EFFECTS BY THE PROPOSED METHODOLOGY

The major potential limitation in the proposed methodology for examining for adverse health effects of contaminants in finished drinking water from planned or unplanned indirect or direct potable reuse is the ability of the chemists to provide the toxicologist a representative concentrate of the organic material present in the water supply. It appears there are a number of technical problems to be overcome before the chemists will be able to provide a representative concentrate of the organic material present in finished drinking water.

Another limitation to the proposed tests, a limitation that is inherent in toxicological testing for many purposes, is the problem of the extrapolation of the data from experimental animals to man. This limitation is perhaps most evident in the estimation of the potential carcinogencity of chemicals. Also the interpretation of the data from mutagenic testing as concerns a potential health risk to man from exposure to components of the finished drinking water that may possess mutagenic properties is an area in which regulatory agencies and the scientific community have not yet reached a consensus. Thus, although considerable progress has been made in recent years in developing the methodology for evaluating the potential mutagenicity of chemicals, the evaluation of what these data mean relative to an adverse health effect in man has lagged considerably behind.

MARGINS OF SAFETY

In the proposed assays for acute, subchronic, chronic (except cancer) neurological, immunological, teratogenic and reproductive effects from exposure to the concentrates of organic chemicals in finished drinking waters a maximum daily intake of a 1000 fold that present in the finished drinking waters is recommended. It is also recommended in those bioassays in which multiple dosing is appropriate, that two lesser concentrations of the organic concentrates be administered. If the toxicological endpoints examined for in these studies do not occur in the animals exposed to the 1000 fold increase in daily intake of the organic chemical in the finished water then, in effect, a safety factor of greater than 1000 exists for these biological effects. For the toxicological endpoints to be examined for in this protocol a safety factor of greater than 1000 exceeds that considered by regulatory agencies and the majority of the scientific community to be the minimal safety factor appropriate for these biological endpoints. If adverse effects are seen at concentrations less than the 1000 fold increase in daily intake of the organic chemicals in the finished drinking water then it is important to establish the no observed effect level (NOEL) for that adverse effect. If necessary, additional dose levels of the organic concentrates should be examined to establish the NOEL for any effect that is seen. If the NOEL does not provide a margin of safety acceptable to the majority of those knowledgeable concerning the type of adverse effect in question, then changes in the treatment procedures or source waters will have to be instituted.

In the case of chemicals which produce cancer the usual procedure is not to use safety factors but rather for the regulatory agency to determine from positive results in animal testing that level of exposure which is calculated to produce an estimated 1 in 10^5 or 10^6 lifetime risks of cancer in populations consuming the chemical or mixture of chemicals. If in the testing of organic concentrates from finished water, the estimated cancer risk exceeded that considered by the EPA to be acceptable then a change in treatment procedures or source water would also be indicated.

RECOMMENDATIONS FOR RESEARCH

1. Of highest priority is research directed to providing a representative organic concentrate for use in toxicological testing.

2. A high priority should also be placed on the development of simple, reproducible and inexpensive tests for monitoring for the potential of organic chemicals in drinking water from planned and unplanned indirect or direct reuse to cause organ system damage including the nervous system and hematopoietic system, reproductive effects, teratogenic effects, decreased immunocompetence, mutation of human somatic and germ cells and initiate and/or promote cancer.

3. Because of frequency of occurrence and concentrations found in surface and ground waters EPA should proceed to set MCL's or perform the necessary research to set MCL's for the following compounds: trichloroethylene, tetrachloroethylene, 1,1-dichloroethane, 1,1,1-trichloroethane, carbon tetrachloride, vinyl chloride, 1,1-dichloroethane, methyl chloride, methylene chloride, benzene, 1,4-dichlorobenzene, 1,3,4-trichlorobenzene, pentachlorophenol, Temik, phthalic acid, diethyl and dibutyl phthalates, atrazine, 2,4-dichlorophenol, toluene, simazine, bis(2-chloroethyl) ether, bis(2-chloroisopropyl)ether, cis and trans dicholoroethylene, 1,1-dichloroethylene, toxaphene and dibromochloropropane.

4. Continue the evaluation of the toxicological implications of substituting other disinfection techniques for chlorine.

5. Examine in rodent bioassays the efficacy of granulated, activated carbon in removing known and unknown organic compounds from drinking water which produce adverse effects in rodents.

6. Investigate treatment techniques in addition to GAC, which may cheaply and effectively remove volatile organics from drinking water (air stripping, etc.).

7. Carry out research in rodents examining the toxic effects of classes of organic compounds isolated from potable reuse waters (i.e., organic acids, amines, chloroform soluble extracts, etc.) with the view of establishing MCL's for these classes of compounds as a means of monitoring for potential toxic effects of materials in finished drinking water and setting design criteria for water treatment.

8. In additon to conducting appropriate descriptive epidemiologic studies, develop a mechanism to conduct long-term prospective studies of communities using renovated water.

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WORK GROUP REPORT/ISSUES PAPER

CHEMISTRY

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FOREWORD

This paper represents the summary and overview of the committee and participants in the Chemistry Workshop. Detailed analyses from which the summary was abstracted are included in the Chemistry Workshop Appendices. The reader is referred to those appendices and the references therein for details not presented in this summary.

INTRODUCTION

The development of water quality criteria for potable reuse and ultimately the use of reclaimed wastewater for potable purposes will require chemical information. The information required includes:

1. The development and evaluation of present data bases with respect to the levels and variability in concentration of organic, inorganic, and radioactive chemicals in municipal wastewaters and other source waters before and after treatment.
2. Chemistry support required for the evaluation of the reliability of the reuse treatment options. This includes collaboration in engineering design and evaluation of individual unit processes for removal of chemicals of concern to human health. The determination of the reliability of the desired treatment process is the primary criteria for the development of monitoring approaches.
3. The evaluation of practical analytical methods necessary to analyze the chemicals present, particularly those which may be of concern to human health.
4. An analysis of isolation and separation processes to obtain water concentrates for bioassay methods and toxicological testing and the identification of specific components in extracts which show toxic properties.

The Chemistry Workshop has discussed the above topics focusing on identification of problem areas and recommendations for chemical procedures to be followed in reuse projects. The Committee considered two fundamental bases for the evaluation of the first three topics.

1. Water quality criteria represented as present maximum contaminant limits (MCL's) and possibly future MCL's.
2. Reliability of the treatment process(es) selected especially if the treatment process(es) is mandated in addition to a set of MCL's.

Water Quality Criteria Represented As MCL's

The water quality-criteria for reuse of wastewater will consist of maximum contaminant limits of organics, inorganics and radionuclides from:

a. present primary and secondary drinking water standards (1,34)

b. future drinking water standards, e.g. from potentially harmful chemicals which include the 129 priority pollutant list and possibly indicators of contamination such as total organic halogen (1-7).

c. special MCL's for chemicals in a specific reuse water location.

It must be noted that there are many organic and inorganic compounds which may be present but that have not been identified and may be of concern to health. For example, the organic compounds identified in drinking waters have been estimated to make up < 10% of the total organic carbon present (3).

Table 1 is an edited list of organic compounds potentially found in water intended for reuse which are of concern to health (1-6). The list of chemicals is edited from data collected by the U.S. National Academy of Science - Safe Drinking Water Committee, the U.S. National Cancer Institute, and a U.S. Government Interagency Research Liaison Committee of Scientists working in evironmental control. The list contains ten organic compounds which have U.S. drinking water standards at assigned maximum contaminant levels. It is expected that future drinking water standards will be developed from the compounds on this list and the 129 priority pollutant list, Table 1 (5). Many of the compounds on Table 1 are on the priority pollutant list, Table 2.

TABLE 1

Compounds of Concern to Health
Potentially Found In
Drinking Water (1-6) - an Edited List

Acrylonitrile
Aldrin
Benzene
Benzo(a)pyrene
α-BHC
β-BHC
*γ-BHC (Lindane)
Bis(2-chloroethyl) ether
Bis(2-chloropropyl) ether
*Bromdichloromethane
*Bromoform
Butyl Bromide
Carbon Tetrachloride
Chlordane
Chlorobenzene
*Chlorodibromomethane
*Chloroform
DDE
DDT

Dibromochloropropane(s)
1,2-Dibromoethane
Dichlorobenzene(s)
1,2-Dichloroethane
Dichlorofluoromethane
*2,4-Dichlorophenoxyacetic acid (2,4-D)
Dieldrin
1,4-Dioxane
1,1-Diphenylhydrazine
Epichlorohydrin
*Endrin
Ethylenethiourea (ETU)
Ethylene Dibromide
Ethylene Oxide
Halogenated phenols
Heptachlor
Heptachlor Epoxide
Hexachloroethane
Kepone

*Methoxychlor
Methylene Chloride (Dichloromethane)
Methyl Iodide
Nitrosamines (e.g. N-nitrosodiphenylamine)
Pentachloronitrobenzene (PCNB)
Polybrominated biphenyls (PBB)
Polychlorinated biphenyls (PCB)
Polynuclear aromatic Hydrocarbons
Simazine
Tetrachloroethylene
Toluene
*Toxaphene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
Trichlorofluoromethane
*2,4,5-Trichlorophenoxypropionic Acid (2,4,5-TP)
Vinyl Chloride
Vinylidene Chloride
Xylene

*Drinking water standard - U.S.

Table 2

EPA list of 129 Priority Pollutants

---

31 are purgeable organics

Acrolein
Acrylonitrile
Benzene
Ethylbenzene
Carbon tetrachloride
Chlorobenzene
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1-Dichloroethane
1,1-Dichloroethylene
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
Chloroethane
2-Chloroethyl vinyl ether
Chloroform

1,2-Dichloropropane
1,3-Dichloropropene
Methylene chloride
Methyl bromide
Bromoform
Dichlorobromomethane
Trichlorofluoromethane
Dichlorodifluoromethane
Chlorodibromomethane
Tetrachloroethylene
Trichloroethylene
Vinyl chloride
1,2-trans-Dichloroethylene
bis(Chloromethyl) ether

46 are base/neutral extractable organic compounds

1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Hexachloroethane
Hexachlorobutadiene
Hexachlorobenzene
1,2,4-Trichlorobenzene
bis(2-Chloroethoxy)methane
Naphthalene
2-Chloronaphthalene
Isophorone
Nitrobenzene
2,4-Dinitrotoluene
2,6-Dinitrotoluene

4-Bromophenyl ether
bis(2-Ethylhexyl)phthalate
Di-n-octyl phthalate
Dimethyl phthalate
Di-n-butyl phthalate
Acenaphthylene
Acenaphthene
Butyl benzyl phthalate

Fluorene
Fluoranthene
Chrysene
Pyrene
Phenanthrene
Anthracene
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-c,d)pyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene
4-Chlorophenyl phenyl ether
3,3'-Dichlorobenzidine
Benzidine
bis(2-Chloroethyl)ether
1,2-Diphenylhydrazine
N-Nitrosodiphenylamine
N-Nitrosodimethylamine
N-Nitrosodi-n-propylamine
bis(2-Chloroisopropyl)ether

11 are acid extractable organic compounds

Phenol
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitro-o-cresol
Pentachlorophenol

p-Chloro-m-cresol
2-Chlorophenol
2,4-Dichlorophenol
2,4,6-Trichlorophenol
2,4-Dimethylphenol

26 are pesticides/PCB's

α-Endosulfan
β-Endosulfan
Endosulfan sulfate

α-BHC
β-BHC
δ-BHC
γ-BHC
Aldrin
Dieldrin
4,4'-DDE
4,4'-DDD
4,4'-DDT

Endrin
Endrin Aldehyde

Heptachlor
Heptachlor epoxide
Chlordane

Toxaphene
Aroclor 1016
Aroclor 1221
Aroclor 1232
Aroclor 1242
Aroclor 1248
Aroclor 1254
Aroclor 1260
2,4,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)

13 are metals

Antimony
Arsenic
Beryllium
Cadmium
Chromium
Copper
Lead

Mercury
Nickel
Selenium
Silver
Thallium
Zinc

Miscellaneous

Total cyanides

Asbestos(fibrous)
Total phenols

Concept of Reliability of a Reuse Water Treatment Facility

The primary concern in the evaluation of a treatment facility for water intended for potable reuse is summed up in the term reliability. Reliability has been defined as a "measure of the degree of successful performance of a facility with respect to required conditions of operation"..."What is the probability that the achieved performance will meet the required performance?" (8)

An alternative or adjunct to MCL's is the specification of a treatment process or processes, with operating conditions set on a site specific basis to insure treatment reliability with minimum health risk.

The required performance will probably consist of MCL's and possibly treatment requirements. The options for increased reliability are shown in Table 3. The term reliability thus includes two interrelated aspects - being able to monitor parameters of interest and developing information to predict variations.

The concept of the reliability of a pilot plant facility was the focus of discussion at the Chemistry Workshop especially as it related to analytical chemical support for evaluation of reuse treatment options.

Concentrating Organics for Bioassay and Toxicity Testing

It is clear that the fourth topic discussed at the Chemistry Workshop related to toxicological procedures to evaluate whether a significant health risk is posed by consumption of reused water is of a different nature than the first three topics considered.

Table 3[a]

OPTIONS FOR INCREASING RELIABILITY TO MEET GIVEN CRITERIA FOR POTABLE REUSE QUALITY

1. Improve quality of influent water
2. Prevent chemical spills
3. Increase removal efficiency of individual treatment processes or a series of processes
4. Add additional treatment processes in series or develop standby processes
5. Do no use treated water when standards exceeded
6. Maintain a detention time to allow more complete chemical analysis
7. Blend effluent with other water

[a] Based on reference 8.

The Toxicology Workshop Committee proposed an experiment where experimental animals would be administered a representative concentrate of the organic chemicals (1,000-fold) present in finished drinking water. The preparation of these concentrates was the fourth area of discussion at the Chemistry Workshop. The choice of a method, or a combination of methods, for concentration is dependent upon such factors as volatility of the organic constituents to be tested, degree of concentration required and biological test system to be used. These factors were carefully evaluated and a set of recommendations was developed to help answer the question.

CHEMICAL COMPOUNDS IN WATER INTENDED FOR POTABLE REUSE - THE DATA BASE

In attempting to develop criteria and standards for chemical constituents in the reuse of renovated wastewater for potable purposes, a broad data base must be developed in order to satisfy the understandable concern that the renovated wastewater will not result in hazards to human health, qualitatively and quantitatively greater than those in our long history of use of "natural" waters as sources for our domestic supplies. To satisfy this concern we must establish 1) an exhaustive data base on the nature and concentrations of chemicals in the (domestic) wastewaters to be renovated, 2) an understanding of the time variabilities of these chemicals 3) the efficacy (and its variability) of the treatment of these constituents, 4) the possible production of byproducts of disinfection or any other unit process, and 5) ultimately the concentrations of the chemicals that will occur in the renovated water delivered to the customer for potable use.

Inorganic Compounds in Water Intended for Potable Reuse

A variety of studies indicate that secondary or biologically treated municipal wastewater results in the addition of a variety of inorganic constituents and a wide range of trace element concentrations (9,10). For many of the trace constituents the range of concentrations is as high as a factor of 100, and these data presumably reflect both variation among and within given secondary effluents. It is thus unlikely that one can define a "typical" municipal secondary effluent with respect to inorganic constituent concentrations. It will be necessary then, to carefully evaluate the concentrations of such constituents in terms of present MCL's for drinking water in order to determine if a specific system is a good candidate for reuse. Table 4 presents inorganic data for the secondary effluent used

TABLE 4. COMPARISON BETWEEN NATIONAL INTERIM PRIMARY DRIKING WATER (NIPDW) REGULATION AND INFLUENT WATER QUALITY #(8)

		Influent Water (01)			
		Second Period		Third Period	
Contaminant	NIPDW MCL	Geometric Mean	98% of Time Less Than	Geometric Mean	98% of Time Less Than
Arsenic, mg/l	0.05	<0.005	<0.005**	<0.005	<0.005**
Barium, mg/l	1.0	0.08	0.14	0.03	0.06
Cadmium, mg/l	0.01	0.026	0.07	0.033	0.15
Chromium, mg/l	0.05	0.14	0.31	0.048	0.11
Lead, mg/l	0.05	0.02	0.051	0.007	0.017
Mercury, mg/l	0.002	0.0016	0.025	<0.001	?
Nitrate (as N), mg/l	10	0.23	1.2	2.8	49
Selenium, mg/l	0.01	<0.0025	<0.0025**	<0.0025	?
Silver, mg/l	0.05	0.003	0.007	0.001	0.006
Fluoride, mg/l	1.4*	1.4	2.0	1.3	1.9
Coliforms, MPN/100ml	1	89	38,000	1.6	195
Endrin, µg/l	0.2	<0.01	<0.01	<0.01	<0.01
Lindane, µg/l	4	0.2	0.9	0.14	0.22
Toxaphene, µg/l	5	<0.01	<0.01	<0.01	<0.01
2,4-D, µg/l	100	<0.01	<0.01	<0.01	<0.01
2,4,5-TP, µg/l	10	<0.01	<0.01	<0.01	<0.01
Methoxychlor, µg/l	100	<0.1	<0.1	<0.01	<0.01
Turbidity, TU	1	42	79	7	54

#Underlined values represent those exceeding MCL
* Temperature > 26.3 C°
** Based on less than 1 in 20 samples analyzed

as the source water for Water Factory 21 (8). Temporal variability can be seen by the geometric mean concentrations for many of the inorganic constituents as the concentrations vary substantially between the two time periods studied.

From such data it is clear that the time variability of a secondary sewage effluent should be evaluated in assessing it as a source water for a reuse system; this can have a substantial impact on the quality of the renovated water product.

It is clear that variabilities encountered in the secondary effluents and the advanced waste treatment and renovation processes must be considered in evaluation of both predictability and reliability. Especially for trace inorganic constituents, which can exist in various states of speciation, it is difficult to predict removals a priori for a given treatment system. Thus, as in the Water Factory 21 study, it is necessary to specifically evaluate this over an extended period of time to insure that the full range of variabilities are encountered and assessed.

Buildup of Constituents on Recycle. There is often concern about the possible buildup of waste constituents in water reuse and recycling. It can be shown readily that a steady-state concentration, rather than an infinite buildup, will eventually be attained, as long as some fraction of the parameter in question is lost in recycle, whether through removal in treatment or the discarding of a portion of the wastewater flow. Such possible buildups on continuous recycle have been considered and equations developed by Long and Bell (11) Dick and Snoeyink (12) and Andelman (13,14). These equations predict the likely steady-state concentrations that may be attained, using information developed from pilot plant and simulated recycle systems.

Monitoring and Assessing Exposures. A wide range of inorganic constituents can and have been measured in wastewater renovation systems. One study by Pahren and Ulmer (15) reported the results of multielement analyses by proton-induced X-ray emission (PIXE) of 70 elements (heavier than aluminum) in effluents from four advanced wastewater treatment plants. Table 5 summarizes the results for those elements detected at least once from the 14 grab samples. In addition, another 46 elements were not detected. For these elements the detection limits were typically 3 ug/L, although a few were as low as 0.3 ug/L. The highest limits were for silicon, 5000; cerium, 20; and praseodymium, 18ug/L. It is clear from Table 5, that indeed a wide range of inorganic elements and concentrations can be detected in renovated wastewaters, as they certainly can in typical public water supplies.

It is important in developing monitoring strategies to utilize the fact that many constituents are log normally distributed over time. Thus, based on actual experience, some constituents will show wide concentration distributions, and others more narrow ones. If the distribution is likely to be wide and/or approach a concentration that could be of health concern (MCL), such a constituent becomes a logical candidate to monitor.

The next question that arises is what action should be taken when specific high concentrations are reached. A constituent which is of concern primarily from the impact of chronic exposure (e.g., lifetime), clearly should be permitted

TABLE 5. Elements Detected in Advanced Wastewater Treatment Effluents (Pahren and Ulmer, 15)

Element	Detection Limit ppb	Percent Detected	Minimum ppb	Median ppb	Maximum ppb
Potassium	100	100	6,530	8,780	17,600
Calcium	100	100	52,500	64,400	96,000
Vanadium	1	57	<1.0	2.0	7.5
Chromium	0.1	57	≤0.1	0.7	12
Manganese	1	71	≤1.0	7.7	412
Iron	1	100	18	33.5	17,900
Cobalt	0.1	7	≤0.1	≤0.1	0.9
Nickel	0.1	100	2.2	9.3	47
Copper	1	93	<1.0	7.1	64
Zinc	1	100	12	26	3,620
Molybdenum	1	79	≤1.0	4.1	15
Silver	1	7	≤1.0	<1.0	2.4
Cadmium	0.1	36	≤0.1	<0.1	5
Lead	0.1	71	≤0.1	2.7	63
Titanium	1	36	≤1.0	≤1.0	33
Gallium	0.1	29	≤0.1	≤0.1	0.9
Rubidium	0.1	93	≤0.1	6.1	11
Strontium	0.1	100	91	432	604
Tin	0.3	21	<0.3	<0.3	7.3
Antimony	0.4	21	≤0.4	≤0.4	9.8
Barium	2.5	93	≤2.5	35.5	77
Thallium	0.3	7	≤0.3	≤0.3	0.5
Arsenic	0.5	93	≤0.5	2.3	9.5
Selenium	1	29	<1.0	<1.0	2.5

to exceed at times the average permissable adverse effect level. In such a case the actual time distribution for such an element should be used to predict the fraction of time (and its uncertainty range) that the constituent is likely to exceed some predetermined value. When it does, this could signal the need for additional sampling, and then assessed as to whether indeed the time distribution concentrations have increased to the point that the mean human exposures have become unacceptably high.

Radionuclides in Water Intended for Potable Reuse

Radionuclides can increase in concentrations in renovated wastewaters as a result of regulated and unregulated discharges into wastewater, (especially unregulated discharges from medical diagnostic tests and therapeutic tests). They can also increase as a result of possible contamination of chemicals used in treatment (16).

It is recommended that pilot demonstration plants and actual potable wastewater renovation systems be monitored for radionuclides to assure that the MCL's promulgated in Drinking Water Regulations (1) be met regularly and with a high degree of assurance. For short lived isotopes, it may be possible to reduce the level of radioactivity to an acceptable level by holding water prior to reuse.

Organic Compounds in Water Intended for Potable Reuse

Whereas quantitative information about the variability of major and trace inorganics in the wastewater to be renovated and the product water has been documented, data on organics is still being developed. Much information is currently available about specific organic compounds that have been detected in various waters with potential for potable reuse.

Much less information is available about organic compounds detected in reclaimed water. A major problem that arises is determining the significance and reliability of available data.

Most of the information on organic compounds has been reported during the last decade when important developments in analytical techniques and instrumentation enabled analysts to obtain specific compound information from water samples by gas chromatography/mass spectroscopy (GC/MS). In the early 1970's, analysts were satisfied to be able to provide qualitative data and very little quantitative data were obtained.

Knowledge acquired during the past decade raises questions about the validity of data that previously were considered to be reliable. These data should be evaluated with consideration for the current state of the art for all steps in the general analytical scheme outlined in Table 6 (17). Evaluation, however, must be an on-going and cannot be a one-time activity, because results that are obtained with the best available techniques today may not be considered to be adequate in light of information developed in the future.

Currently, the best information that can be provided with a reasonable effort is a list of organic compounds by GC/MS reported to be present in waters of concern (municipal wastewaters, groundwater, surface waters, drinking water, etc.), the number of times they were detected and the concentrations if reported. Although this information is better than nothing at all, more useful and reliable information could be obtained from careful evaluation of data source documents.

Frequency of occurrence information is inherently skewed because many studies have been designed to detect only a group of selected compounds. Even studies that were designed

Table 6

General Analysis Scheme for Organic Pollutants

Source Water

↓

Sample

↓

Isolation

↓

Sample
Preparation

↓

Sample
Analysis

- Chromatographic Separation

and

- Spectroscopic Identification

to attempt to detect and identify broad spectrums of organic compounds present in a particular water sample produce skewed frequency of occurrence, because analytical techniques used for most studies to date provide information only about compounds that are gas chromatographable and analyzed by GC/MS. Information about non-volatile compounds is almost non-existent.

The current scientific literature could provide much useful information if reports were evaluated with respect to the current state-of-the-art and considering the factors listed in Table 7. Because of the large volume of current information, a more feasible approach might be to use a comprehensive computerized data base to develop a list of organic compounds detected in the type of water of interest. The "WATERDROP" system of EPA (18) is a positive step in this direction.

Some of the compounds that are identified will be generally regarded as compounds known to occur and of concern because of potential harmful effects. The identification of other compounds on a list will be questionable, and the original data source should be evaluated with consideration of current knowledge of factors affecting data validity. Of primary concern is whether the identification was confirmed or was only a tentative identification. Criteria for GC/MS confirmation are presented in Table 8 as this is the primary analytical method used for identification.

Table 7

Factors to be Considered in Developing Reliable Information About Organics in Source and Treated Water for Potable Reuse

I. Purpose of Study

II. Description and History of Samples, including available general water quality parameters

III. Sample Collection

   A. Sampling Frequency - Does the Collection Method Characterize the Water Quality, e.g., On-Line vs. Grab Samples?

   B. Quality Assurance Program

IV. Sample Preservation

   A. Storage Temperature

   B. Light Exposure

   C. Sample Component Interaction

   D. Storage Time

   E. Sample Pretreatment

V. Sample Isolation

   A. Selectivity of Isolation Procedure

   B. Efficiency of Isolation Method

   C. Quality Assurance Program

VI. Sample Preparation

   A. Fractionation Schemes

   B. Effectiveness of Sample Preparation Steps

   C. Quality Assurance Program

VII. Sample Analysis

   A. Confirmation of Compound Identification (See Table 8)

   B. Quantitative Analysis of Compounds Identified

   C. Accuracy and Precision of Method

   D. Quality Assurance Program

VIII. Artifact Formation

TABLE 8

Criteria for all GC/MS Confirmation

1. The mass spectrum of the unknown compound matched the mass spectrum of a standard compound run on the same instrument under the same GC/MS conditions.

2. The relative retention time (RRT) of the unknown compound agree with that of standard compound run under identical GC conditions.

3. The mass spectrum agreed with the spectrum found in the NIH/EPA Mass spectral search systems (MSSS).

4. The mass spectrum agreed with the mass spectrum found in the literature

5. The mass spectrum agreed with a mass spectroscopist's interpretation. (In cases where this was the only confirmatory technique, an authentic standard was not available at the time, nor was there a spectrum in the computer data bases or the literature).

If a compound meets criteria 1&2 it is listed as a positive (P) identification (ID). If it meets criteria 3,4 or 5, its identification is listed as tentative (T).

A compound was considered "detected" in the extracts when the same compound, as determined by GC/MS data, either was absent in the blanks or was significantly above the level of that found in the blank extracts.

The existence of quantitative data are more limited than qualitative data; available quantitative data need to be evaluated with respect to recovery information and quantitation techniques, in addition to the factors used to evaluate qualitative data. Nevertheless, the value of qualitative information about occurrence of organic compounds known to affect health is useful because it may indicate a potential problem area.

The best currently available information about specific organic components of reclaimed water with potential for reuse are the recent studies conducted at Water Factory 21 (8) . Other studies currently underway will provide additional information within the next two years (19,20).

Table 9 shows the identity of the organic compounds identified in the influent and effluent from the treatment process of Water Factory 21. Over 25 trace organic materials were in sufficient concentration to permit quantification and removal efficiency to be measured. The average removal levels are summarized in Tables 10 and 11 for two different study periods. The confidence interval is generally "quite small" and removal is over 90% for the October 1976-March 1978 period whereas the confidence interval is much wider and removal is less consistent for the March 1978 to January 1979 period. In fact, a decrease or an increase in the concentrations of certain organics during the latter test period is unclear (see m-xylene). [This is partially attributed to the decrease in influent concentration in the second test period when industrial waste segregation and activated sludge treatment replaced the trickling filter influent to the facility.] Aromatic hydrocarbons were reduced 2 orders of magnitude and chlorobenzenes, phthalates and PCB's were also reduced by 60-90% yet chlorinated ethanes, ethylenes and diisobutylphthalates and lindane were not reduced.

Table 9

COMPOUNDS IDENTIFIED IN WF-21 INFLUENT (Q1) AND EFFLUENT (Q9 AND Q22B) (8)

Aromatic Hydrocarbons

benzene
[e]toluene
[e]ethylbenzene
[e]p-xylene
[e]m-xylene
[e]o-xylene
[e]1-ethyl-4-methylbenzene
[e]1-ethyl-3-methylbenzene
[e]1,3,5-trimethylbenzene
[e]1-ethyl-2-methylbenzene
[e]1,2,4-trimethylbenzene
[e]1,2,3-trimethylbenzene
C_4-benzenes
indane
methylindanes

[e]naphthalene
[e]1-methylnaphthalene
[e]2-methylnaphthalene
C_2-napthalenes
C_3-naphthalenes
styrene
biphenyl
phenanthrene/anthracene
[e]methylphenanthrene (4 isomers)
phenylnonane isomers
phenylundecane isomers
C_3-biphenyl isomers
C_6-biphenyl isomers
pyrene/fluoranthene

Synthetic Chlorinated Compounds

[e]methylene chloride
[e]trichloroethylene
[e]tetrachloroethylene
[e]1,1,1-trichloroethane
[e]1,1,2-trichloroethane
[e]hexachloroethane
[e]chlorobenzene
[e]1,2-dichlorobenzene
[e]1,3-dichlorobenzene
[e]1,4-dichlorobenzene

[e]1,3,5-trichlorobenzene
[e]1,2,4-trichlorobenzene
[e]PCB Aroclor 1242
pentachlorophenylmethylether
tetrachlorophenylmethylether isomers
trichlorophenylmethylether isomers
dichlorophenylmethylether isomers
[e]carbon tetrachloride
lindane
tetrachlorobenzene isomer

Chlorination Products

[e]chloroform
[e]dichlorobromomethane
[e]chlorodibromomethane
[e]bromoform
[e]dichloroiodomethane
[e]1,1,2,2-tetrachloroethane
[e]β-chlorostyrene isomers

[e]chlorobromoiodomethane
[e]1,1,1-trichloroacetone
[e]chloroxylene
[e]chlorobromopentanone
[e]bromoketone
[e]methylchlorobenzene
[e]α,β-dichloroethyl benzene

(continued)

Table 9 (continued)

Natural Products

terpenes
terpene alcohols
fenchone
fenchyl alcohol
trans-beta-farnesane
heptaldehyde

[c]lauric acid methyl ester
[c]myristic acid methyl ester
[c]peritadecanoic acid methyl ester
   isomers
[c]heptadecanoic acid methyl ester
stearic acid methyl ester
palmitic acid methyl ester

Phthalate Esters

[b]dimethylphthalate
diethylphthalate
[b]di-n-butylphthalate

[b]di-isobutylphthalate
[b]bis(2-ethylhexyl)phthalate

Miscellaneous Compounds

camphor
isophorone
p-t-amylphenol
octylcyanide
hexylcyanide
other alkylcyanide
[b]methyl-2-(p-chloro-phenoxy)-
   2-methyl-propionate

o-isomer clofibrate metabolite
methylbenzoate
[b]tolualdehyde isomers
ethylphenol
2-chloropyridine
[b]benzaldehyde
[b]pentadecane
[b]octadecane
[b]acetophenone

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[a]Priority pollutants are underlined

[b]Found in effluents also

[c]Identified after methylation

October 1977 - December 1978 study where activated sludge effluents were split, treated by chlorination (Q9) and reverse osmosis (Q22B).

TABLE 10 . REMOVALS OF ORGANIC SUBSTANCES THROUGH AWT TREATMENT DURING SECOND PERIOD (October 1976-March 1978) (8)

					Percentage Removal	
Contaminant	Avg.[a] Inf. Conc.* (Q1)	95% Conf. Interval	Avg.[b] Eff. Conc.* (Q9)	95% Conf. Interval	Average	95% Confidence Inter. for Avg
COD	141		17		88.2	87.6 to 88.8
Methylene chloride	17	13-23	1.6	1.1-2.3	90.6	85 to 94
1,1,1-Trichloroethane	4.7	3.5-6.3	0.07	0.4-0.13	98.5	97 to 99
Trichloroethylene	0.9	0.6-1.4	0.02	0.004-0.1	97.8	91 to 99
Tetrachloroethylene	0.6	0.3-1.1	0.05	0.01-0.19	91.7	67 to 98
Chlorobenzene	2.5	1.4-4.3	0.05	0.03-0.08	98.0	96 to 99
1,2-Dichlorobenzene	2.4	1.4-4.0	0.03	0.01-0.08	98.8	96 to 100
1,3-Dichlorobenzene	0.68	0.4-1.3	0.01	0.001-0.07	98.5	91 to 100
1,4-Dichlorobenzene	2.1	1.3-3.4	0.02	0.003-0.14	99.0	94 to 100
1,2,4-Trichlorobenzene	0.46	0.2-1.1	0.01	0.002-0.06	97.8	86 to 100
Ethylbenzene	1.4	0.8-1.6	0.03	0.02-0.05	97.9	96 to 99
Naphthalene	0.57	0.3-1.0	0.03	0.02-0.04	94.7	90 to 97
1-Methylnaphthalene	0.86	0.5-1.4	0.04	0.03-0.06	95.3	91 to 97
2-Methylnaphthalene	1.0	0.6-1.7	0.02	0.005-0.09	98.0	92 to 99
Dimethylphthalate	16	11-23	1.7	0.03-8.6	89.4	69 to 96
Diisobutylphthalate	2.9	1.4-5.9	0.74	0.01-3.8	40.0	0 to 94
Bis-[2-ethylhexyl]phthalate	28	19-42	3.2	0.6-18	88.6	60 to 97
PCBs measured as Aroclor 1242	3.3	2.2-4.8	<0.3	-	> 91	-

*μg/l except COD which is in mg/l

a) Average of at least 10 determinations each except 3 determinations for Dimethylphthlate.

b) Average of at least 7 determinations each except 3 determinations for Dimethylphthlate.

TABLE 11. REMOVALS OF ORGANIC SUBSTANCES THROUGH AWT TREATMENT DURING THIRD PERIOD (March 1978-January 1979) (8)

Contaminant	Avg.[a] Infl. Conc.* (Q1)	95% Conf. Interval	Avg.[b] Eff. Conc.* (Q9)	95% Conf. Interval	Percentage Removal Average	 95% Confidence Inter. for Avg.
COD	47		12		73.8	72.2 to 75.4
1,1,1-Trichloroethane	3.25	2.1-5.0	0.20	0.07-0.55	94	83 to 98
Trichloroethylene	0.74	0.4-1.4	<0.1	-	>86	-
Tetrachloroethylene	1.67	1.3-2.2	0.83	1.6-3.9	50	22 to 68
Chlorobenzene	0.14	0.11-0.18	0.05	0.03-0.08	65	40 to 80
1,2-Dichlorobenzene	0.64	0.47-0.83	0.02	0.007-0.06	97	93 to 99
1,3-Dichlorobenzene	0.16	0.12-0.21	<0.01	-	>97	-
1,4-Dichlorobenzene	1.9	1.6-2.1	0.012	0.004-0.04	99.4	98.2 to 99.8
1,2,4-Trichlorobenzene	0.11	0.07-0.18	<0.01	-	>99	-
Heptaldehyde	0.10	0.06-0.18	0.03	0.008-0.11	71	-5 to 92
Ethylbenzene	0.043	0.03-0.06	0.014	0.008-0.02	67	41 to 82
m-Xylene	0.035	0.03-0.05	0.02	0.01-0.04	43	-9 to 70
p-Xylene	0.015	0.01-0.02	0.012	0.007-0.02	20	-45 to 56
Naphthalene	0.033	0.02-0.06	0.01	0.007-0.02	70	0 to 91
1-Methylnaphthalene	0.008	0.004-0.017	<0.02	-	?	-
2-Methylnaphthalene	0.01	0.004-0.02	<0.02	-	?	-
Styrene	0.048	0.03-0.09	0.003	10^{-4}-0.005	94	45 to 89
Dimethylphthalate	4.8	3.8-6.1	0.47	0.23-0.95	90	81 to 95
Di-n-butylphthalate	0.79	0.54-1.2	0.33	0.15-0.74	58	7 to 81
Diisobutylphthalate	4.7	3.9-5.7	0.27	0.09-0.82	94	84 to 98
Bis-[2-ethylhexy]phthalate	11	8.6-14	3.1	2.2-4.4	72	60 to 80
Polychlorinated biphenyls measured as Aroclor 1242	0.47	0.38-0.57	<0.3	-	>36	-
Lindane	0.14	0.13-0.15	<0.05	-	>67	-

*ug/l except COD which is in mg/l and was measured at location Q8.

a-Average of at least 20 determinations each.

b-Average of at least 14 determinations each.

At Water Factory 21, the time variability of some trace organics had been investigated (Table 10 and 11). A geometric mean concentration for many of the organic compounds varied substantially between the concentration in the source and finished waters. This can have a substantial impact on the quality of the product water. Predictability and reliability of treatment processes need to be understood for these compounds. A monitoring strategy to utilize the fact that many constitutents are log normally distributed over time is needed.

A constituent which is defined as related to health (Tables 2 and 3) and is near an MCL or action limit should be carefully monitored on a routine basis (e.g. THM's). This should be augmented by broad spectrum analyses to routinely monitor a reuse water for organics as compounds which may be health related may occur from time to time in reuse water situations. Specific information on the exact amount of required samples per time period should depend on the variability of organics in the source water utilized and the specific treatment processes utilized. In each of these different analytical protocols a quality assurance program must be included in future work. This last point was a major frustration of the review of the present data base.

CHEMISTRY SUPPORT REQUIRED FOR THE EVALUATION OF THE RELIABILITY OF THE REUSE TREATMENT OPTIONS

An important activity associated with the development of water reuse facilities is the evaluation of treatment processes and combinations of processes. This activity is usually associated with pilot-scale studies, generally considered to be an essential component of water reclamation projects. While members of the engineering community most often lead these studies, participation by other disciplines, including chemistry, is increasingly important. As the process proceeds from pilot-scale to full plant scale, the role of chemical monitoring and technology may take on different but equally important roles.

It should be understood that reuse of water for potable purposes will place unusual requirements on the process design engineer, and on the analytical chemist. The reliability of reuse facilities (Table 3) will be critically dependent on monitoring and process control procedures. Moreover, acceptance of the concept of wastewater reuse for potable consumption will depend, in part, on assurances to the public that the product water meets the highest standards of purity. These considerations will require an elaborate and sophisticated analytical monitoring and process control technology which is unusual in the water treatment industry.

Guidance for the decision of where to locate a reuse facility begins with a complete evaluation of the influent source water. Besides monitoring the influents, source water monitoring of the industrial discharges to the source is appropriate. Correct monitoring of the quantity and quality of the input waters may be as important as control of the treatment process especially where batch industrial wastes discharges are involved. Knowledge of the type of industry, its wastewater quantity and quality would help develop an optimum monitoring strategy. This was indicated in the studies at Water Factory 21, where segregation of industrial wastes helped decrease the influent concentrations (8). At present this type of information has not been developed. Initial studies are underway (19). Analytical monitoring programs to evaluate influent source water will be described in the next Section.

Progression of Analytical Monitoring Program in Reuse Projects

It is recommended that the development of a reuse treatment scheme contain the following elements:

1. Broad Spectrum Analysis of the Source Water.

   This survey of the influent water to the proposed reclamation plant must utilize comprehensive, advanced separations and analysis methods. It should emphasize an evaluation of temporal variations, and attention should be given to organic, inorganic, and radioactive substances. Compounds or elements with known toxicity should be searched for and quantified when identified. Industrial and domestic source waters should be characterized to determine if segregation of waste streams is necessary.

2. Development of an Analytical Protocol for Pilot-Scale Evaluation of Candidate Treatment Processes.

   The essential elements of this program must include the factors shown in Table 7 for developing reliable analytical information. Highlighted conditions are:

a. Sampling frequency sufficient to detect changes in unit process performance as a function of temporal variations in source water quality.

b. Sampling methods to insure water quality integrity and representation of the sample site.

c. Sample preservation to prevent microbial and chemical degradation.

d. Sample isolation and analysis by an acceptable analytical procedures.

e. An adequate quality assurance program.

3. Development of an Analytical Protocol for Full Scale Plant Operation.

In addition to the elements listed in 2 above, this protocol should include utilization of on-line, rapid response analytical methods where appropriate. The development of these methods is likely to proceed steadily as reuse facilities are expanded in number and complexity.

4. Choice of Chemical Parameters to be Monitored at Reuse Facilities. This subject is treated in more detail in other sections of this report. However, it should be noted that analytical protocols to be used in (1 through 3) above should include measurement of substances which may not be regulated through Maximum Contaminant Levels (MCL's). Available data suggest that municipal wastewaters contain many organic compounds at levels above those acceptable for protection of human health. Although no MCL's

may exist for these substances, treatment processes should nevertheless be evaluated in terms of their removal. One approach used by McCarty and co-workers (8) is to adopt analytical criteria for removal for organic substances of concern ("hypothetical MCL's"). These criteria were then used to evaluate reliability of unit processes. As an aid to future evaluation of reuse projects, it is recommended that an appropriate body (e.g., National Academy of Science) should address this issue, and consider the development of a list of water quality criteria by which to standardize such evaluations.

5. Evaluation of Innovative Treatment Processes.

Another important activity associated with reuse of water for potable purposes should be the development of new treatment processes. As interest in the control of refractory toxic substances increases, attention to the development of new unit processes will increase accordingly. These processes should be evaluated with the same care and attention to quality assurance as noted above for more traditional methods.

ANALYTICAL METHODS NEEDED FOR ASSESSING ORGANIC CHEMICALS OF CONCERN TO HEALTH

Analytical methods to monitor inorganic and radioactive constitutents in reused water and MCL's to guide the use of analytical data have been developed over the last 25 years. Analytical methods to monitor concentrations of part-per billion (ug/l) and part-per-trillion (ng/l) of organic chemicals in reused water are now being developed as are MCL's for organic chemicals in drinking water.

Analytical methods that are needed for organic chemicals can be defined as specific and non-specific:

1. Specific Analytical Methods to Monitor For Individual Chemicals.
   a. Chemicals based upon health concerns especially for monitoring compounds with MCL's.
   b. Multiple chemicals by "broad spectrum" analysis to screen many specific chemicals utilizing chromatography and mass spectroscopy to characterize the sample.
2. Non-specific Analytical Methods to collectively measure a large number of organic compounds. Non-specific analyses are used to develop surrogate analysis, to represent the combination of many organic chemicals and for rapid monitoring of chemical loading.

The widely varying concentration of trace amounts of the organic chemicals of health concern present within the complex matrix of water for reuse makes quantitative determination of even a few chemicals extremely difficult. Process control of a reuse water facility based upon quantitative analysis of all the possible compounds present is now not feasible.

Sampling

An accurate evaluation of the source water and the reliability of treatment processes for waters intended for reuse depends upon the sampling routine. There are basically four types of sampling approaches commonly in use: grab sampling, batch composite, continuous composite sampling and finally continuous on-line sampling. Minute-to-minute, continuous on-line sampling and analysis is recognized as collecting the most representative samples. This approach is now only possible for inorganic chemicals and some nonspecific organic parameters such as UV and fluorescence. First generation continuous composite water sampling and sequentially timed grab sampling methods are being developed for inorganics and specific organic analyses. Continuous composite water samplers that can collect a sample without head-space have been developed for purgeable organics (21). Also continuous composite sampling by resin accumulators (22) or continuous liquid-liquid extraction (23) are being developed for non-purgeable organics. For these methods subsequent laboratory chromatographic analysis is needed (see Table 6). An example of an automated grab sampler for refrigerated collection of water samples and a continuous compositor resin accumlator for the analysis of non-purgeable organics is being developed by Midwest Research Institute (18). The automatic grab sampler can be utilized to make batch composite samples.

It is recommended that on-line continuous analysis be developed for non-specific analysis and grab and continuous compositors be developed for inorganics and specific organic analysis. Grab samples must augment composites for specific analyses as grab samples can observe the presence of high concentrations (spills) and temporal variability of short duration. This variability would be averaged out in composite samples which present longer term average values. As previously described, since minimal information is now available on the temporal variation of organics in reuse source water, within treatment processes,and in the product water, development of sampling methods should be a priority item.

Strategy for Monitoring Specific Organic Chemicals

A principle consideration is whether one desires to analyze for a specified limited number of compounds or a broad range of compounds. The former case is parameter oriented, while the latter case is broad spectrum in approach. Certainly, when monitoring to comply with a regulation of a maximum contaminant level, (for example chloroform) the parameter approach is appropriate. When a more complete characterization of a given water is to be made, then the broad spectrum approach to obtain a profile of the organic present in the water is warranted. In this case, procedures and methods to maximize the number of compounds identified are used.

Analysis of Water and Wastewater for Specified Organic Pollutants

A series of 13 test procedures for 114 specific organic priority pollutants have been developed and have been proposed for use in the National Pollution Discharge Elimination System Program (NPDES) (24), for State certification, and for compliance monitoring under the Clean Water Act (25). These procedures employ conventional gas chromatographic and liquid chromatographic techniques for quantiative measurement of specific organic compounds in effluents. In addition to the relatively low cost gas chromatographic procedures employing conventional detectors, higher cost GC/MS procedures are also provided for routine monitoring of pollutants. High pressure liquid chromatography (HPLC) which has developed significantly in the last few years, is proposed for certain parameters where state-of-the-art packed column gas chromatography has been unable to achieve adequate separation for quantitative measurement. Each method has been evaluated for applicability to a variety of industrial and municipal effluents, and interlaboratory studies are underway on each of the methods to develop a formal definition of accuracy and precision and to define the limit of detection in the effluents.

As additional compounds are identified as having a potential adverse effect on human health these procedures should be expanded. It is anticipated that analytical schemes of this type will be utilized in treatment plants where reuse water is intended for potable consumption. Quality assurance programs should be developed for each of priority pollutant analytical schemes. A detailed discussion of the analyzed methodology for priority pollutants is contained in the Appendix.

Broad Spectrum Chromatographic Screening Methods for the Simultaneous Analysis of Many Organic Compounds

Whereas, each method above included a selective isolation and concentration and cleanup steps in preparation for final analysis, a broad spectrum general screening method is an approach for the analysis of organic compounds that are isolated by a particular method and evaluated from the same sample matrix. The isolation method utilized defines the sample collected. Each isolation procedure will have its own compound selectivity. For example, the primary selectivity can be based upon volatility, (purge and trap analysis), adsorption (XAD-resin accumulators) or liquid-liquid extraction into a solvent. Table 12 defines principal isolation methods available for use.

The complex group of trace organics in the final sample extract is chromatographed and a "sample profile" or "fingerprint" of the compounds is obtained. The fingerprint constitutes an information pattern in each chromatographic analysis. When many profiles are plotted together in the same manner, chromatographic profiles can be compared and differences noted. This approach is being used for the study of drinking water (26). When gas chromatography/mass spectroscopy of a set of similar gas chromatographic profiles is obtained, identification of the sample components can be made. If an internal standard is placed in the sample, an order of magnitude estimation or a relative concentration of the different compounds represented in different locations on the profile can be obtained (26).

Quantitative analyses can be completed during a broad spectrum analysis when precision limits for quantitative response of the method are determined. An approach to profiling compounds by semi-quantitative concentration ranges has been developed and is used in South Africa (28). This method classified the number of compounds into four concentration ranges; A, > 10μg/L, B, 1 to 10 μg/L, C, 0.1 to 1μg/L, and D < 0.1μg/L. The treatment procedures use the pollution index to compare the number of compounds in the influent and effluent water.

Table 12

METHODS OF ISOLATION OF ORGANIC CHEMICALS FROM AQUEOUS SAMPLES FOR GENERAL SCREENING PROCEDURES AND SPECIFIC ANALYSIS

Isolation Techniques	Collection Phase
Vapor Phase	
1. Headspace	Gas
2. Stripping	Solid
Water Phase	
1. Liquid-liquid extraction (LLE)	Liquid
2. Adsorption by solids	Solid
a. Carbon adsorption method (CAM)	
b. Macroreticular resins (MRR)	
c. Chromatographic liquid phases	
d. Porous polyurethane foam	
3. Freeze concentration	Solid
4. Reverse osmosis	Aqueous-Concentrate

Based upon reference 17.

It is recommended that protocols for broad spectrum analytical methods be designed and that detailed evaluation of precision and accuracy of the sample profile methods be developed to define the capabilities and limitations of this evolving technology.

Nonspecific Organic Analysis

In order for water reuse to be accepted as a source of potable water the need for stringent control of organic contaminants will be necessary. It may not be cost effective to meet the above by routinely monitoring each specific organic compound (e.g. priority pollutant analysis). Indeed, it is the premise of this section that in a well characterized and well designed reuse system of the future, specific organic pollutants may need only be occassionally monitored. The frequency will depend on the variability of the source and the reliability of the treatment process. Further, monitoring by specified analytical procedures could be dictated by excursions from preset limits as measured by nonspecific on-line procedures as UV absorbance. Although broad spectrum chromatographic analysis has been described above as a method for specific organic chemical analysis, it can also be used as a non-specific information pattern, a fingerprint to indicate changes of water quality in a qualitative or semi-quantitative format (26,28). The preset limits would be developed in the design stage of a reuse facility. Nonspecific organic analyses are the collective measurement of a large number of organic compounds by a particular analytical method. The purpose of nonspecific organic analysis(es) should be defined in terms of specific goals. These goals should include one or more of the following:

1. To determine if surrogate parameter(s) for specific organic compounds of health concern can be developed.
2. To aid in the design of a unit treatment process.
3. To monitor a unit process(es) or a treatment plant.

4. To be used in operational control of a unit process treatment plant. Goals 2-4 measure loading of organics and temporal changes of influent/effluent levels.

Nonspecific analyses have been used in reuse research. Various non-specific parameters have been correlated with each other (29). However, what is lacking are correlations to specific organics compounds of health concern. It is quite probable that these nonspecific methods for organic compounds will provide essential data for design, monitoring and control in direct reuse situations. The extent to which these methods are used for these purposes will depend on the development of instrumentation which is reliable, provides on-line measurements, and is economically feasible.

The automation of procedures is of paramount interest for several reasons. Once a procedure is automated, then although the initial expense of equipment may be somewhat higher, the cost of manpower is reduced, thereby reducing the per-sample cost proportionately and increasing the frequency of data collection. It is equally important that emphasis be given to those procedures which can be modified to give on-line or continuous measurements of water quality.

Monitoring of TOC should be considered. As a process monitor, TOC does indicate changes in influent and effluent concentrations, process trends, and general organic changes. These will be helpful in design, monitoring and possibly operating a unit process or treatment plant. The reliance on such a parameter may very well depend on the availability of low-cost reliable and continuous monitoring equipment.

The determination of total organic halogens (TOX) as purgeable (POX) and nonpurgeable (NPOX) may be important parameters where water for potable reuse is concerned. Organohalogen monitoring may provide health related information concerning synthetic organic chemicals as well as formation of organochlorine and organobromine compounds when using chlorine as the disinfectant. The development of on-line instruments should be considered as a goal for the future.

Whereas BOD_5 and COD do not hold promise as monitoring or control parameters, total oxygen demand (TOD) and electrochemical organic content (EOC) analyzers are of potential use in the monitoring and in the control of unit processes. Additional work is needed in EOC analyzer development in order to provide reliable low cost instrumentation and potential on-line monitoring capability (30).

Spectroscopic technniques such as UV and fluorescence respond in general to double bonds aromatics and compounds with unshared π electrons. Nonspecific spectroscopi procedures may be utilized as indicators of the change in organic chemicals through a treatment system. Spectroscopic techniques may offer simple procedures for screening the quality of source water and water that passes through the treatment processes. They may also in some cases indicate when a spill up-stream or other pertubation in water quality has occurred.

Many analytical procedures are available which are class specific. For example cholinesterase inhibition is a surrogate for chemicals of health concern e.g. organophosphate and carbamate pesticides. The adaptation of chemical class analysis at very low levels of compounds in water requires considerable development. This may be another monitoring approach for treatment design and process control.

Precursor chemicals are those that react with disinfectants to produce byproducts. A functional precursor definition, the trihalomethane formation potential (THMFP), has been defined to determine the maximum THM concentration under appropriate test conditions which can be developed for each water supply. Therefore, THMFP is a measure of haloform precursors. The trihalomethane formation potential or a more rapid modification of this determination should be evaluated as a process evaluation for disinfection by chlorination. At present nonspecific organic analyses are not recommended as surrogate parameters for specific organic compounds of health concern. Correlations as yet do not exist for this purpose. Of all the nonspecific organic analyses, organic halogen measurements hold the most promise to be developed for this purpose. Cholinesterase inhibition and THMFP are nonspecific parameters directly related to health effects. But, since THMFP takes greater than 3 days to run, a quicker estimation method is needed.

Thus, in the next ten years it is felt nonspecific procedures and broad spectrum chromatographic profile method will be used for operational monitoring and control of reuse facilities, leaving specific compound analyses for less than routine samples and during situations where these methods indicate a problem situation. Therefore the objectives of using these procedures is to provide as much continuous monitoring as possible of the loading of organics and temporal changes of influent/effluent levels.

CONCENTRATION OF ORGANIC COMPOUNDS FOR BIOASSAY METHODS AND TOXICITY TESTING

The usefulness of biological toxicity tests of concentrates of organic constituents separated from reclaimed water is dependent upon the degree that the concentrate represents the actual organic materials present in the water sample. That is, in order to use biological test data for estimation of total hazard or risk, the organic concentrate must be representative (with respect to chemical species and concentration ratios) of all the organic substances present in the water of concern. Currently no single concentration procedure exists that is capable of concentrating all the organic materials actually present in water samples in this manner. Such a procedure may never be possible. (See Appendix)

Therefore, a principal recommendation is to use several techniques each of which is designed to concentrate or separate a portion of the organic spectrum. Concentrates from the several techniques may then be either blended or individually tested for biotoxicity. It may be profoundly more simple and economical to use several different concentration methods, however, this raises the specter of missing a significantly toxic substance because of the selectivity of the concentration method.

The following are a list of recommendations:

1. If it is necessary to achieve concentration of several thousand gallons per day, given the information now available, it is recommended that column adsorption techniques be used because of their basic simplicity and high throughput.

XAD-2 and XAD-8 or 7 resins, either in series or separately are recommended for use. A thorough evaluation of the separation capabilities of these resins, and their operational parameters is recommended. It has been found that non-polar constituents can be separated quantitatively by XAD-2 (18) and that approximately 50% of the aquatic humic material can be separated by XAD-8 (31). The recovery of polar constituents of intermediate molecular weight is judged as variable from low to high (18,31). A particularly troublesome burden with the use of resins is the preparation of clean resin. This "art" must become a science.

As a complementary or parallel technique, it is recommended that reverse osmosis be used for preparations of concentrates for biological testing. (Humic materials and high molecular weight constituents are separated efficiently by this procedure. Large-scale reverse osmosis facilities can be constructed).

2. It is recommended that development of isolation methods be encouraged, particularly for those chemicals in the intermediate molecular-weight range that may not be adequately isolated by the adsorption or reverse osmosis process.

3. It is recommended that methods to evaluate and compare different concentration techniques be developed and applied. This will require increased emphasis on chemical analysis to identify much of the organic material in the concentrates by broad spectrum analysis. This will also require comparison of the techniques by determining the recovery of a series of compounds of various solubilities selected to include a range of chemical classes, functional classes, functional groups, and molecular weights. Aquatic humic materials (including that after reaction with chlorine) should be included in this evaluation.

4. It is recommended that a quality assurance program be developed and applied to the concentration of organics for biological testing to ensure high significance of the biological test data.

Several problem areas exist that are critical to evaluating the significance of biological tests of organic concentrates. These problems related to the factors previously described for developing reliable information from chemical analyses, Table 7. These critical problems are outlined here as they apply to biological tests:

1. Recovery. Are the organic constituents concentrated or isolated from the water sample representative of the actual organics present? What fraction or fractions are recovered? What chemical species or classes are missed or not recovered by the concentration process?

2. Concentrate stability. What is the optimum storage procedure for a concentrate to maximize stability and minimize biological and chemical degradation?

3. Artifacts. What constituents are present in the organic concentrate because of the separation or concentration procedure? What constituents are present or altered due to interaction of chemical species as they are concentrated or to reaction of chemical species with the separations media? What artifacts are formed during concentrate storage?

4. Humic substances. Does the concentration method "denature" or alter humic substances and, consequently, change biological effects?

5. Organic-inorganic interface. Methodologies may separate metal ions from metal-organic complexes. Is this significant?

6. Overlap. If several concentration methods are used, what is the significance of the overlap or redundant separation of organic constituents that may be collected by two or more of the separations procedures?

7. Salt. A major problem with concentration techniques in which the water is removed from the organic constituents, e.g. lyophilization, vacuum distillation, reverse osmosis, and ultrafiltration, is that of desalting the concentrate.

8. Volatile constituents. Volatile constituents pose a special problem principally due to storage of concentrates and difficulty in preparing concentrates from large volumes of water (i.e. several thousand gallons per day). Volatile constituents are more easily identified by current technology and, thus, can be biologically tested as individual compounds or blended with concentrates of nonvolatiles and constituents of intermediate volatility for biological testing.

9. Disinfectant considerations. Destruction of chlorine with sulfite also destroys mutagens (31, 32). The effect of other dechlorination agents on the mutagenic activity of drinking water is not known. How can residual chlorine or other disinfectants, e.g. chlorine dioxide, ozone, be removed from the water to be concentrated without altering the composition of organic constituents or destruction of toxic materials?

The following is proposed in the spirit of a "best guess" approach to the problems posed to the Chemistry Workshop by the Toxicology Workshop: Develop a 1000-fold increase in all concentrations with thousands of gallons of water processed each da .
As a first approach to development of a separation scheme the following steps should be carefully tested in parallel and in series.

— Isolate volatiles - use purge and trap
  - analyze and reconstitute
— Isolate non-polar and low molecular weight organics - use XAD-2 resin
— Isolate humics and polars - use XAD-8 or reverse osmosis
— Isolate humics and others - use reverse osmosis
— Isolate intermediate molecular weight range - needs method development.

The alternate schemes must be completely evaluated.

OVERALL SUMMARY

The chemistry issue paper has discussed four topics to present guidance with respect to the chemical aspects of indirect and direct potable reuse.

1-the present chemical data base

2-the chemical support needed for evaluation of the reliability of reuse option.

3-the practical analytical methods to evaluate the reuse option.

4-The isolation and separation methods needed for bioassay methods and toxicity testing.

Criteria for determining acceptable potable reuse quality represented as maximum contaminant limits (MCL's), and reliability of treatment option(s) were the bases of this discussion.

The existing water quality criteria for reuse of wastewater should consist of the present drinking water MCL's for organics, inorganics and radionuclides, future MCL's from the present list of potentially harmful chemicals (e.g. priority pollutants), possible indicators of contamination as organic halogens and site specific MCL's. Information needs to be obtained on the unknown organic and inorganic chemical species present in the source water and water treatment byproducts, e.g. disinfectant byproducts. The primary emphasis of the workshop's deliberations were on organic species since they, are the most complex and the least understood in reused water.

The summary and recommendation for each select area are as follows:

1. Development and evaluation of a chemical data base is needed with respect to variability in influent concentration, efficiency of removal and the concentrations delivered to the consumer of organics, inorganics and radionuclides. At present a limited quantitative data base exists for inorganics at Water Factory 21 which shows a geometric mean concentration varying between two time periods and predictability of operation of unit processes is extremely

difficult. The data base for the variability of organics is not well documented. Methods to develop the qualitative and quantitative data base for organics are outlined in the report. Monitoring and computer access of the data base needs to be developed.

2. Chemistry support of reuse facilities requires the on-going evaluation of the reliability of the treatment methods. The analytical criteria for inorganics, organics and radionuclides of health concern must be developed. It is important in developing monitoring strategies to utilize the fact that many constituents are log normally distributed over time. Also, with each and every analytical protocol a quality assurance program must be completed.

3. Reliable sampling and analytical methods, needed for assessing organic chemicals of concern to health, include specific analytical methods for individual and multiple chemicals to monitor variability of organic constituents in reuse waters and nonspecific analytical methods to help develop surrogate analysis and rapidly monitor chemical changes and loadings. Priority research areas are the development of composite and continuous sampling methods, broad spectrum analytical protocols with associated quality assurance systems, and on-line non-specific analysis. Major emphasis should be placed on the examination of the unknown or inadequately known organic fraction including screening methods for non-volatile pollutants and an understanding of toxicological concentrates.

4. Currently no single concentration procedure exists that is capable of concentrating all the organic materials actually present in water samples for optimum toxicity testing. Several concentration techniques of high throughput should be tested either in series or separately to develop a method. Column absorption techniques (XAD resins) and reverse osmosis holds the most promise. Continued research in developing reliable methods for the concentration of organics for toxicity testing should be encouraged.

The following is a list of specific monitoring recommendations which are highlighted in the report.

1. Sampling procedures and methods must be compatible with the analytical scheme to be used. If validated, these procedures can include vapor phase and water phase isolation methods. Examples are: grab, batch composite, continuous composite, and continuous on-line. Development of sampling methods should be a priority item for research.

2. Analytical approaches to be taken include:

    a. Measurement of specific compounds (and parameters) via a methodology which is narrow in scope. An example is the methods for the analysis of priority pollutants. This approach should be used where qualitative and quantitative information is desired about select classes or groups of compounds. Quality assurance programs for these procedures should be developed and employed.

    b. Measurements of compounds via methodology which is broad spectrum in scope. The objective is to determine the presence of many compounds simultaneously. Protocols for broad spectrum analysis should be developed . Precision limits for quantitative response of the methods should be determined and quality assurance programs for these procedures should be developed.

        (1) Gas chromatographic profiling to fingerprint specific compounds, to determine the general level of contamination, and to observe the variability of these compounds should be used. The use of gas chromatography/mass spectroscopy (GC/MS) is necessary for confirmation of qualitative identification of compounds as described in Table 8. Detailed evaluation of the precision and accuracy of the sample profile method should be developed to define its capabilities and limitations.

        (2) The use of surrogate parameters such as dissolved organic carbon, UV and fluorescence should be used to (continuously) monitor unit processes. It is hoped that in some select cases, it may be possible to correlate surrogate parameters with the presence

of specific compounds. A significant change in surrogate concentration may indicate the need to increase the rate of sampling and analysis for specific organic compounds.

(3) The development of laboratory certification programs for those parameters and compounds regulated under the Clean Water Act, e.g., coliforms and trihalomethanes should be developed. Under the requirements of the act, this program should be extended to all parameters and compounds pertaining to potable reuse water.

(4) For situations where sampling and analysis is to be performed in the absence of specific regulations, quality assurance procedures should be employed by involved laboratories. These quality assurance procedures will be in accordance with acceptable practices and will include the following: collection and preservation of water samples; selection of concentration procedures; standardization of concentration procedure; documentations and record keeping, and reporting of results (see Table 7).

Future Analytical Requirements

1. Solve problem areas of sampling, storage and matrix effects for priority pollutant analytical procedures and future procedures as developed.

2. Develop gas chromatography and gas chromatography/mass spectroscopy as well as liquid chromatography and liquid chromatography/mass spectroscopy broad spectrum methods for pollutants, both for water samples and in order to evaluate toxicological concentrates.

3. Develop liquid chromatographic screening methods for nonvolatile pollutants for use at water treatment plants, in research laboratory screening and to understand toxicological concentrates.

4. Develop rapid analytical methods and sound quality control program for the analyses of specific organic compounds and the broad spectrum analysis of organic compounds.

5. Develop totally automated methods for specific organic and inorganic chemicals, to include on-line sampling and sample extraction methodology.

6. Develop totally automated methods for monitoring of non-specific parameters with detection limit below 1 ug/L.

7. Establish training programs for treatment plant chemists.

8. Establish a source of certified primary standard solutions for all regulated chemicals and compounds.

9. Determine on an intralaboratory basis using representative raw source water and finished water the precision and accuracy for each method, and determine the minimum detection limits on representative samples.

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Work Group Report
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MICROBIOLOGICAL CRITERIA AND STANDARDS FOR POTABLE REUSE OF WATER

INTRODUCTION

General

For over 100 years, microbiological contaminants were the principal issue of concern to public health officials responsible for the quality of public water supplies. This concern resulted from the recognition that acute microbial diseases are occasionally transmitted to broad segments of the population via the water supply route. Since the raw wastewater of a community must be presumed to be contaminated with infectious agents of all kinds, the potable reuse of water requires that there be a complete rethinking of traditional means of process monitoring and control for maintaining microbiological quality. Once again, issues of microbiological control must be a principal concern.

The World Health Organization has defined "direct reuse" of water as "the planned and deliberate use of treated wastewater for some beneficial purpose, such as irrigation, recreation, industry, the recharging of underground aquifers, and drinking."[1] Indirect reuse, on the other hand, occurs "when water already used one or more times for domestic or industrial purposes is discharged into fresh surface or underground waters and used again in its diluted form." In this sense, rivers and lakes often receive untreated or treated domestic wastewater and at the same time, serve as sources for potable water supplies. For example, the wastewater discharge of the City of Pittsburgh into the Ohio River will become a small percentage of the river flow reaching Cincinnati which in turn uses the river as a raw water source for its public water supply. It has been calculated that surface water supplies for U.S. cities serving populations over 25,000 may contain up to 16 percent wastewater during periods of normal flow conditions with considerably greater wastewater percentage during low flow.[2] Depending on flow and location, the water in the Ohio River may be as high as 17 percent wastewater effluent while the lower Rhine River, which serves as a raw water supply source for six million people, may reach 40 to 100 percent wastewater effluent at times.[3] Even waters believed to be pristine, such as high altitude mountain streams and lakes, may contain the waste discharges of man and animals; such waters are often used as a public water supply without any thought to their being contaminated with waste material. Thus, indirect reuse of water has been a fact of life throughout the world for many years.

The assessment of the impact or hazard associated with the transmission of infectious agents via the waterborne route is difficult. The presence of microorganisms in or on living things does not necessarily mean that the host will develop disease. Likewise a waterborne disease usually occurs in a population without concomitant recovery of the organism from the water because of technical problems associated with the recovery of specific pathogens *in situ*. However, in outbreaks where an etiologic agent is not recovered, an epidemiologic investigation may still be able to implicate water as the vehicle of transmission. Whether or not an individual becomes diseased depends upon a series of complex interrelationships between the host and the infectious agent. Specific variables include: (1) numbers of the invading microorganism (infectious dose), (2) the organism's ability to cause disease (pathogenicity), (3) the degree to which the microorganism can cause disease (virulence), and (4) the relative susceptibility of the host. In general terms, infectious microorganisms have a potential for causing disease only if the organism is sufficiently virulent to overcome the host's defenses.

Infectious Agents in Raw Domestic Wastewater and Disease

Any attempt to catalog the infectious agents or microbial pathogens of man which conceivably could be present in raw domestic wastewater would produce an unbelievably long list. The tremendous variety of infectious agents that might be present is derived principally from the feces and other body discharges of infected human and animal hosts. The occurrence and relative density of these agents in raw domestic wastewater will depend upon a number of complex factors; therefore, it is impossible to say with any degree of assurance what the general characteristics of a particular wastewater will be with respect to infectious agents. Actually, it can be expected to vary from one country to another, from one community to another, from one day to another, and perhaps from one hour to another. Important variables influencing the occurrence and density of infectious agents in raw domestic wastewater include the sources contributing to the wastewater, the general health of the contributing population, the existence of "disease carriers" in the population, and the ability of infectious agents to survive outside their host under a variety of environmental conditions.

The principal infectious agents that may be found in domestic raw wastewater may be classified within four broad groups: bacteria, viruses, protozoa and helminths. Table 1 lists some of the infectious agents, along with their associated disease. It should be noted that this list is representative and is not intended to be all-inclusive; further, the infectious agents listed have not been detected in raw domestic wastewater with the same degree of frequency. In addition, it is impossible to give the density of infectious agents that might be found or expected in raw domestic wastewaters with any degree of accuracy. It is possible, however, to illustrate the variation and/or the order of magnitude of the density of certain infectious agents that might be encountered in raw domestic wastewater, e.g.,

Table 1. Infectious Agents Potentially Present in Raw Domestic Wastewater

	Organism	Disease
I.	Bacteria	
	Shigella (4 spp.)	Shigellosis (Bacillary Dysentery)
	Salmonella typhi	Typhoid Fever
	Salmonella (~1700 spp.)	Salmonellosis
	Vibrio cholerae	Cholera
	Escherichia coli	Gastroenteritis
	Yersinia enterocolitica	Yersiniosis
	Leptospira (spp.)	Leptospirosis
	Campylobacter	Gastroenteritis
II.	Viruses	
	Enteroviruses (71 types)	Gastroenteritis, heart anomalies, meningitis
	Hepatitis A virus	Infectious hepatitis
	Adenovirus (31 types)	Respiratory disease
	Rotavirus	Gastroenteritis
	Reovirus	Not clearly established
	Norwalk-like	Gastroenteritis
III.	Protozoa	
	Entamoeba histolytica	Amebiasis (Amoebic Dysentery)
	Giardia lamblia	Giardiasis
	Balantidium coli	Balantidiasis (Balantidial Dysentery)
IV.	Helminths	
	Ascaris lumbricoides	Ascariasis
	Ancylostoma duodenale	Ancylostomiasis
	Necator americanus	Necatoriasis
	Ancylostoma (spp.)	Hookworm
	Strongyloides stercoralis	Strongyloidiasis
	Trichuris trichiura	Trichuriasis
	Taenia (spp.)	Taeniasis
	Enterobius vermicularis	Enterobiasis
	Echinococcus granulosis	Hydatidosis

Salmonella, up to $10^4/\ell$; protozoan (cysts), up to $10^5/\ell$; helminth (ova), up to $10^3/\ell$; enteric virus (pfu), up to $10^5/\ell$. Such information should be considered with respect to the inadequacies associated with the detection and enumeration methods associated with some infectious agents. For example, the observed density of enteric viruses may be one to two logs lower than the actual density due to the limitations of the current virus recovery and cultivation procedures.

Waterborne Disease Outbreaks

The importance or major concern associated with the presence of infectious agents in wastewater is their possible waterborne transmission and potential for causing disease. Waterborne disease outbreaks in the U.S. are usually reported to the Center for Disease Control, USPHS, Atlanta, GA, by state health departments but may be reported to the U.S. Environmental Protection Agency. Although this reporting is voluntary and known to be incomplete, the information gathered does give a measure of the importance of the water route as a means of disease transmission. Table 2 tabulates the reported waterborne disease outbreaks in the U.S. between 1946 and 1975.[4] During this 29-year period, 101,860 cases of disease were associated with 480 outbreaks. Further, during the 7-year period 1971 through 1977, 19 to 34 outbreaks were reported each year with a total of 36,757 cases.[5,6] *Salmonella* has been a major identified etiological agent as indicated by the finding that waterborne *S. typhi* was responsible for 12 percent of the total number of cases of typhoid fever in the U.S. during the period 1971 through 1974.[7] It should be noted that the identification and investigation of waterborne outbreaks is basically a function of state and local health departments that typically do not have resources to identify all outbreaks that occur within their jurisdiction. Therefore, under-reporting is certain but the extent is unknown. Work now being funded by EPA suggests that perhaps about 10 percent of the outbreaks that occur may actually be identified and reported.

Table 2. Outbreaks of Waterborne Disease in the U.S., 1946-1975 [4]

Disease	Causal Agent	Outbreaks	Cases
Bacterial			
Typhoid fever	*Salmonella typhi*	58	836
Shigellosis	*Shigella* (spp.)	49	10,869
Salmonellosis	*Salmonella* (spp.)	16	16,801
Gastroenteritis	*Escherichia coli* (Enteropathogenic)	5	188
Leptospirosis	*Leptospira* (spp.)	1	9
Tularemia	*Francisella tularensis*	2	6
Viral			
Infectious hepatitis	Hepatitis A virus	67	2,201
Poliomyelitis	Poliovirus	1	16
Protozoal			
Dysentery	*Entamoeba histolytica*	5	75
Giardiasis	*Giardia lamblia*	22	5,473
Unknown etiology			
Gastroenteritis		254	65,386

Among the waterborne bacteria causing disease, members of the genera *Shigella*, *Salmonella*, and *Escherichia* have the greatest health impact. Viruses, particularly those associated with infectious hepatitis and gastroenteritis, are also recognized as important waterborne infectious agents. Of the parasites, i.e., protozoa and helminths, the most significant waterborne disease appears to be giardiasis and to a lesser degree, amoebiasis, caused by *Giardia lamblia* and *Entamoeba histolytica*, respectively. Since the late 1960's, the number of reported outbreaks and cases of giardiasis has increased significantly. Between 1946 and 1975, there were 22 outbreaks with 5473 cases of giardiasis.[4] Contrasted to this 29-year period, the number of outbreaks and cases of giardiasis for the seven-year period 1971-1977 was 20 and 6787, respectively.[6,7] In one outbreak in Rome, NY, in 1974-75, more than 5300 persons may have become ill. The large number of outbreaks and cases of gastroenteritis of unknown etiology is also worth noting; between 1946 and 1977, 53 percent of the total number of outbreaks were so classified.[4,7]

In considering the above statistics, it is worth noting that between 1971 and 1977, more outbreaks occurred with semi-public water supply systems (58 percent) than with municipal (30 percent) and individual systems (12 percent).[6,7] Further, for the same period 47 percent of the outbreaks occurred with untreated surface or groundwater; 32 percent were associated with deficiencies in treatment; 14 percent were because of deficiencies in distribution systems; and 7 percent were caused by miscellaneous reasons.

INDICATORS AND INFECTIOUS AGENTS

Indicator Systems

The most logical approach for determining the possible presence of infectious agents in water would be to test for the infectious agents directly. Considering the different types of infectious agents that might be present in a raw domestic wastewater (Table 1), treated effluent, receiving water, public water supply, etc., this approach would require the use of a vast number of tests, some of which involve complex, time-consuming, and often insensitive procedures. Further, the density of different infectious agents will vary in different wastewaters and waters. This variability, which makes the detection of infectious agents difficult and somewhat unreliable, is a function of intestinal infections which can occur at different times in the contributing warm-blooded population. In recognition of these constraints, it has been common practice to use a microbial indicator or surrogate to indicate fecal contamination of water.

Because the source of most infectious agents is the feces of man and other animals, the focus has been on the use of organisms (indicators) which occur naturally in the feces of warm-blooded animals. The use of a microbial indicator, commonly found in fecal matter, will determine the presence or absence of fecal contamination in water and at the same time, suggest the presence or absence of infectious agents. To be a satisfactory indicator, an organism or group of organisms should be present in the feces of warm-blooded animals at a density greater than that for any infectious agent so as to be easily and unambiguously detectable. There should be a positive correlation between the indicator and fecal contamination. The response of the indicator and the various infectious agents to different environmental conditions and treatment processes, e.g., disinfection, should also be correlatable. Although there are other requirements for an acceptable indicator, these are perhaps the most important. Over the years, a number of different microbial indicators have been proposed, with some more commonly used than others.

Total Coliforms. Since it was proposed some 70 years ago, the most widely used microbial indicator group for determining the presence and intensity of fecal contamination in water has been the coliform bacteria. The density of total coliforms in raw domestic wastewater may be as high as 10^9/100 mℓ but in the U.S., the density is most commonly in the range of 10^6 to 10^8/100 mℓ.[9,10]

Over the years, the total coliform test has become an accepted indicator of fecal contamination and there is ample evidence to justify this acceptance. The occurrence of any coliform bacteria in a water should be a signal of possible fecal contamination and the likelihood that infectious agents may be present. Because of its general acceptance, even with respect to monitoring the adequacy of water treatment, the total coliform indicator system is the test on which the maximum microbiological contaminant level (MCL) is expressed in the National Interim Primary Drinking Water Regulations. In practice,

> the absence of total coliforms in a potable water supply has been considered adequate evidence of a safe supply. It should be noted, however, that there have been instances where the total coliform test has not signaled the presence of waterborne *Salmonella* and *Giardia*.[11] Further, it is recognized that the coliform group of bacteria is less resistant to chlorination, the most widely used means of water disinfection, than some infectious agents, e.g., protozoan cysts and enteric viruses.
>
> Fecal Coliforms. The use of the total coliform group of bacteria as an indicator of fecal contamination has been criticized because some strains of coliforms are widely distributed throughout the environment; these strains, therefore, are not directly associated with fecal matter. These non-fecal strains of coliforms may be found in wastewater. To overcome this criticism, the fecal coliform test has been used as perhaps a more exact measure of fecal contamination of water. Fecal coliforms constitute over 90 percent of the group of total coliforms normally found in the feces of warm-blooded animals.[10] The density of fecal coliforms in raw domestic wastewaters ranges from 10^5 to 10^6/100 mℓ. Although fecal coliforms may be more directly related to fecal contamination and have certain other advantages over the total coliform indicator system, e.g., less regrowth in contaminated water, there remains the need to correlate the occurrence of fecal coliforms in water with the presence of waterborne infectious agents. In defense of the total coliform indicator system, it may be pointed out that in addition to its demonstrated value in assessing the occurrence of infective agents in water, the results

of a total coliform test may be conservative in that it offers a margin of safety not associated with the fecal coliform test.[10]

Fecal Streptococci. The fecal streptococci group of bacteria has been used as a measure of fecal contamination for approximately 50 years. Raw domestic wastewater may contain up to 10^6 fecal streptococci/100 mℓ.[10] As a group, the fecal streptococci include strains having variable survival rates and others having little significance as an indicator of fecal contamination because of their occurrence and reproduction outside of the intestinal tract of warm-blooded animals. In certain waters, fecal streptococci may exist for extended periods of time. However, this group of indicator bacteria has been used frequently to determine the source of water contamination and as supplementary information along with the results of the fecal coliform determination. Using the density difference between fecal coliforms and fecal streptococci (FC/FS ratio), it is possible to predict if a recent source of contamination is from human feces, i.e., domestic wastewater, or from farm animals, cats, dogs, birds, etc.

Clostridium perfringens. This spore-forming anaerobic bacterium is commonly found in the feces of warm-blooded animals and its use as an indicator of fecal contamination has been rigorously supported in certain areas of Europe. However, the organism is also regarded as being ubiquitous in nature.[11] Being a spore-former, *Clostridium perfringens* will persist longer in water than non-spore-forming bacteria such as the coliforms. In this sense, it has been suggested that this bacterial indicator may be useful in detecting past contamination or as a tracer of fecal contamination. *Clostridium perfringens*, being a spore-former, has also been suggested as an indicator of adequate disinfection of a water; on the other hand, the spores may be too resistant to disinfectants to be useful.

Standard Plate Count. This technique, as currently used, gives a measure of the number of heterotrophic bacteria in water which can grow at 35°C. The Standard Plate Count, which may be as high as 10^{10}/100 mℓ in raw wastewater, appears to be valuable in providing additional information relative to infectious agents that may be present in water. There are other plate count techniques which give colony counts which are 5 to 10 times higher while microscopic enumeration of bacteria in water may yield densities 50 to 100 times higher than the Standard Plate Count. These density differences between cultural methods and direct count relate to the presence of fastidious organisms in the water and the inability to differentiate viable from non-viable organisms. It is generally accepted that many of the bacteria present in water have not been cultured or identified to date; the health significance of these bacteria is an open question.

Other Indicators. A number of other indicators have been proposed, some of which have been used to a limited extent. For the most part, inadequate information is available so that their suitability or utility as an indicator of fecal contamination is uncertain. The use of *Pseudomonas* (spp.) as an indicator group has been proposed but because they are ubiquitous in nature and actively reproduce in potable water and even distilled water, this indicator has not generated much attention.[11] Also, *Pseudomonas* may persist for an extended period of time in water and, as a result, has been observed in the absence of coliform bacteria.

Lactobacilli, *Bifidobacterium*, and *Bacteroides* have also been proposed as indicator groups.[10] These non-spore-forming anaerobic bacteria occur generally at higher densities in feces than the aerobic bacteria and frequently outnumber the coliforms. Unfortunately, not all humans shed a detectable number of lactobacilli and *Bifidobacterium* in fecal matter.

This observation, plus poor survival in the aquatic environment, limits their utility as indicators of fecal contamination. Enumeration methodology is also a problem with these anaerobic bacteria, particularly in the case of the *Bacteroides* which are obligate anaerobes.

The use of species of *Aeromonas* as an indicator of fecal contamination of water has been suggested. Members of this genus of bacteria are widely distributed in nature with some being infectious to aquatic anaimals.[11] Many are capable of long survival in the aquatic environment. For these and other reasons, *Aeromonas* has not generated much attention as an indicator. It has recently been proposed that acid-fast bacteria might be attractive as an indicator of disinfection efficacy, in that their sensitivity to chlorine is similar to that of several enteric viruses which have been observed to have a resistance greater than that of the coliforms.[12] Acid-fast bacteria appear to be a common inhabitant of raw domestic wastewaters.

It has been proposed that bacteriophage, particularly coliphage, might be a suitable indicator of enteric viruses and perhaps other infectious agents in water. Depending upon the host culture, raw domestic wastewater may contain up to 10^6 coliphage/100 mℓ.[13] Although limited, data exist which indicate that there may be a correlation between coliphage and enteric viruses in water; other data indicate that coliphage would be an inadequate indicator. Noncoliphage, such as *Serratia marcescens* and staphylococcal bacteriophage, have also been proposed as an indicator of enteric viruses.[13] The bacteriophage may be particularly useful in evaluating removal or inactivation of viruses by wastewater and water treatment processes. It would appear that much remains to be learned about bacteriophage in wastewater and water.

Finally, the measurement of fecal sterols, ATP and bacterial endotoxins in water have been studied as rapid indicators of fecal contamination or as providing possible supplementary information. For example, the *Limulus* endotoxin assay has been investigated for correlation with conventional bacterial indicator tests.[14] The significance and interpretation of endotoxin results in environmental samples is questionable and the utility of this test needs further evaluation.

Ideally, an indicator should be selected that, when present in concentration above an established limit, indicates that the ingestion of the water poses an unacceptable risk of infecting the consumers. The results of the tests should be available prior to final distribution (real-time indicator) and if the limit is exceeded, the water should receive additional treatment before use.

Infectious Agents

The rationale for using the indicator approach in determining the microbiological quality of a water requires that the value and reliability of any indicator be assessed with respect to the infectious agents which might be present in a water, i.e., bacteria, viruses, protozoa, and helminths.

Bacteria. The most common infectious agents in raw domestic wastewater are perhaps the enteric bacteria and of these, members of the genus *Salmonella* apparently occur most frequently. This genus contains a large number of species that are pathogenic to man, including *S. typhi*, *S. paratyphi*, and *S. typhimurium*. It is estimated that one to two million people in the U.S. are infected by *Salmonella* annually. Members of the genus have frequently been isolated from feces, wastewaters, receiving waters and even finished water supplies on occasion. *Shigella* organisms are one of the chief etiological agents of bacillary dysentery, with *S. dysenteriae* infections being perhaps the most serious. Actually, there are four species of *Shigella* of which two, *S. sonnei* and *S. flexneri*, are the most common. Sixty percent of the reported cases of shigellosis are caused by *S. sonnei* while 10 percent are caused by *S. flexneri*.[5] There are few reports of *Shigella* bacteria being detected in wastewater, even though *Salmonella* may be routinely isolated. Evidence indicates that survival of *Shigella* in wastewater is relatively short. Although contaminated water can be a vehicle for transmission, shigellosis is also spread by person to person contact. Although *E. coli* is part of the normal indigenous flora in the intestine of man, this organism can at times cause gastroenteritis. Disease producing strains have been characterized as "enteropathogenic," "enteroinvasive," and "enterotoxigenic." While all of these strains are rare in the United States, the enterotoxigenic strains, through contamination of food or water, are a major cause diarrhea in travelers to developing countries. In addition to these three classes of pathogenic bacteria, others of lesser frequency of occurrence may also be present in raw domestic wastewater. This group might include *Vibrio*, *Clostridium*, *Leptospira*, *Mycobacterium*, *Campylobacter* and *Yersinia* species. Definitive information is needed on the occurrence, distribution and survival of these organisms in the environment.

There is ample evidence to justify the use of the total coliform and fecal coliform tests as reliable indicators of the presence of these bacterial infectious agents in water. In the case of water reuse, it would seem desirable in analyzing water samples taken after treatment to supplement coliform data with the Standard Plate Count as a means of monitoring the general bacterial quality of the water and to detect possible interference with the coliform test.

Viruses. Over 100 distinct serotypes of viruses may be present in raw domestic wastewater (Table 3) and the density in the U.S. may be on the order of 10^4 viral units/ℓ.[15] Enteric viruses are those which multiply in the intestinal tract and are shed in the feces of infected persons. Because the infection level in the contributing population tends to increase in late summer and early fall, the density of enteric viruses in raw domestic wastewater will also be greatest during this period. The dominant virus types in wastewater will also vary with time and in general, reflect the nature of the infections within the contributing population. Vaccine poliovirus strains, however, are a common, year-round inhabitant of wastewater; for this reason, it has been suggested that the poliovirus may serve as a suitable indicator of virus quality.

Of the many enteric viruses that may be detected in wastewater, those associated with infectious hepatitis and gastroenteritis warrant special attention because of the existing epidemiological evidence that they may be spread via the water route. Unfortunately, these viral agents have yet to be cultivated in the laboratory; thus, there is no recovery method available so that their density in wastewater and water supplies may be determined. This situation exists in spite of the advances that have been made during recent years in the techniques for concentrating viruses from water and in culturing them in the laboratory. Although these improved techniques have increased the sensitivity of virus recovery, leading to the finding of higher numbers in water than previously reported, there is still a need for a better understanding of the reliability, limits of detection and precision of the methodology associated with the recovery and culturing of enteric viruses. It should also be noted that with todays procedures, a two-week period is required before a water sample can be recorded as negative for enteric viruses.

Table 3. Human Enteric Viruses Potentially Present in Water*

Virus Group	No. of Types	Disease Caused
Enteroviruses		
Poliovirus	3	Paralysis, meningitis, fever
Echovirus	34	Meningitis, respiratory disease, rash diarrhea, fever
Coxsackievirus A	24	Herpangina, respiratory disease, meningitis, fever
Coxsackievirus B	6	Myocarditis, congenital heart anomalies, rash, fever, meningitis, respiratory disease, pleurodynia
New Enteroviruses	4	Meningitis, encephalitis, respiratory disease, acute haemorrhagic conjunctivitis, fever
Hepatitis Type A	1	Infectious hepatitis
Gastroenteritis virus (Including Norwalk-like)	?	Epidemic vomiting and diarrhea, fever
Rotavirus	?	Epidemic vomiting and diarrhea, chiefly of children
Reovirus	3	Not clearly established
Adenovirus	>30	Respiratory disease, eye infections

*Adapted from Ref. 15

There is also the problem of detecting and enumerating viruses in water which may be attached or embedded in particulate matter. The significance of virus clumping or aggregation with respect to virus recovery and enumeration in water and the interpretation of such information in terms of infectious unit or dose also needs further examination.

From the above, it should be obvious that much remains to be learned about viruses in the water environment and their enumeration and interpretation.

Until such time that a reliable virus enumeration procedure is available and the results can be interpreted with some degree of confidence, justification for establishing a virus standard for potable water would be difficult.

Without an acceptable virus enumeration procedure and standard, some kind of indicator or surrogate must be used to assess the viral quality of water. There are, in general, many more fecal bacteria in raw domestic wastewater and contaminated water than there are enteric viruses. This would indicate that some type of bacterial indicator of fecal pollution might also serve as an indicator of viruses in water. This application appears doubtful insofar as coliform, streptococci, and perhaps other bacteria are concerned because viruses have been observed to be more resistant to the environmental conditions associated with water and to wastewater and water treatment processes than the conventional bacterial indicators. However, because of the uncertainty that exists, this relationship needs further study. In addition to coliform bacteria, other recognized indicator systems, such as *Pseudomonas*, coliphage, acid-fast bacteria and the Standard Plate Count and perhaps new ones, should be studied as potential indicators of the viral quality of water.

Protozoa. There are two major stages in the life cycle of protozoa, trophozoite and cyst. With respect to human infection, the active, feeding stage or trophozoite resides in the intestine while the resting form or cyst appears in the feces of infected individuals. These cysts, which may be fecally excreted in large numbers, are responsible for the transmission of infection. The protozoa of greatest concern because of disease transmission through water are *Entamoeba histolytica*, *Giardia lamblia*, and to a lesser extent, *Balantidium coli*. The reservoir of infection for E. *histolytica* is man. Although endemic amebiasis is rare in the U.S., carrier type infections may be found among the population. These carriers may shed a large quantity of cysts, e.g., 10^7/day.[16] Thus, E. *histolytica* cysts, measuring 10-12 μm in size, may be found in raw domestic wastewater. In recent years the protozoan of greatest health concern has been the flagellate *Giardia lamblia*. The cysts of this protozoa are ovoid, 8-12 μm long and 7-10 μm wide. Giardiasis appears to be endemic in the U.S. in that *Giardia* can be frequently identified in stool samples; 10^8 cysts may be excreted daily by infected individuals.[16] The density of *Giardia* cysts in raw domestic wastewater may be as high as $10^5/\ell$ at a prevalence rate in the human population of 25 percent. Both amebiasis and giardiasis may be spread by person to person contact. *Balantidium coli* is a ciliated protozoa and is believed to be worldwide in distribution. Both the trophozoite and cyst stages can be infective for man. The trophozoite measures 30-150 μm by 25-120 μm while the diameter of the cysts is 40-60 μm. The incidence of balantidiasis in humans is low; contact with swine appears to be the major route of transmission of the disease. The potential exists, however, for the disease to be spread through water contaminated with fecal matter.

There is no standard procedure for the detection and enumeration of intestinal protozoan cysts in water at the present time. Procedures which have been used with G. *lamblia* and E. *histolytica* rely on cyst concentration by microporous filtration and analysis of the concentrate by microscopic examination. In the case of E. *histolytica*, microscopic examination may be supplemented with cultural techniques. Because of difficulties in detection and identification of cysts and in determining their viability in the case of G. *lamblia*, today's procedures are not recommended for routine monitoring of water. At the present time, there does not exist an acceptable methodology to support a standard for pathogenic intestinal protozoa in water. The total coliform and fecal coliform tests measure fecal contamination of water with the results being interpreted as an indicator of the microbiological contaminant level. Thus, without direct reference, the results of the coliform and fecal coliform tests are taken as a measure of the infectious protozoan population in water but the adequacy of this interpretation is unknown. It is generally recognized that protozoan cysts are more resistant to environmental conditions than coliform organisms and perhaps most other bacteria; the same observation applies to the resistance of protozoa cysts to water disinfection. Thus, coliform organisms do not appear to be an acceptable indicator for *Giardia lamblia* or *Entamoeba histolytica*. In fact, water outbreaks of giardiasis have occurred where the microbiological quality was indicated as acceptable, based upon results of coliform tests. There is a need to develop a reliable procedure for the routine detection of protozoan cysts in the case of water reuse and/or to identify an appropriate and reliable indicator system.

Helminths. Potentially, there are some two dozen helminths, belonging to either the phyla Platyhelminths (flatworms) or Nematoda (roundworms), which may cause human infections by being transmitted through water (Table 1). Improved sanitary conditions have greatly reduced the prevalence of helminth infections among the human population. However, water transmission of such helminthic infections as ascariasis and trichuriasis is still possible when the infective stage of the helminth is ingested with water. There are other helminths which gain entrance to humans by way of skin penetration, e.g., the hookworms (*Necator* and *Ancylostoma*) and schistosomes (*Shistosoma*); the presence of these helminths in contaminated water may be transmitted to humans during bathing. Many of the helminths have complex life cycles, including a required stage in intermediate hosts; with some helminths, the infective stage is either the adult or a larval form while with the others and more common, it is the eggs or ova which are important in the spread of the infection through water. The ova of intestinal parasitic worms are excreted in the feces of infected individuals; consequently, they may be found in raw domestic wastewater. In fact, the ova of *Ascaris lumbricoides*, the whipworm *Trichuris trichiura*, the tapeworm *Taenia saginata*, and others have been observed in wastewater. In considering the infective stage of the different helminths that might be found in wastewater and water, it is significant to note that the ova and perhaps other stages in the life cycle of helminths often have a high degree of resistance to many environmental conditions. Further, the smallest size of any of the helminth infective stages would appear to be approximately 0.02 mm. This would mean that the infective stage of helminths should be removed by filtration, providing the effective pore size is approximately 0.01 mm. However, conventional water filtration may not be effective in removing the infective form of all helminths because some adult and larval forms of helminths, such as schistosomes and nematodes, are motile and, as a result, may penetrate a sand filter.

Direct detection of helminths in water is not normally performed because of procedural problems. Like the protozoa, the coliform organisms may not be an adequate indicator for helminths because of increased resistance of ova to certain environmental conditions and water disinfectants. Thus, there is need to develop a reliable method for detecting helminths in water directly or to identify an acceptable indicator system.

REMOVAL AND/OR INACTIVATION OF INFECTIOUS AGENTS

It seems appropriate to consider this particular aspect because one of the more likely rationales upon which the microbiological criteria of water reuse might be based is the required degree of treatment. This might take the form of recognizing that certain treatment unit operations and processes should be included in any comprehensive wastewater/water treatment scheme which is intended to produce a product water for potable reuse. Such an approach does not nullify the need to establish a rigorous and reliable microbiological monitoring or surveillance program, employing procedures either to detect infectious agents directly or to determine their possible presence through the use of suitable indicator systems. Data on the microbiological quality of wastewater effluents are deficient. An exhaustive effort should be made to identify and quantify all the infectious agents which occur in wastewater effluents at various sites. Only in light of this kind of base information can a rational evaluation of treatment performance be conducted. Base line microbial information on source water for potable reuse must continue to be gathered for selected infectious agents so as to be alert for unsatisfactory trends in the source water quality that might impact on treatment processes.

The initial treatment of raw domestic wastewater for water reuse may continue to involve those processes normally included in conventional wastewater treatment, i.e., primary treatment or sedimentation and biological secondary treatment with final clarification. In addition to preparing the wastewater for terminal disinfection, it is generally recognized that primary and secondary treatment accomplishes removal of infectious agents in raw domestic wastewater, i.e., bacteria, viruses, protozoan cysts, and helminth ova, but that removal is variable at best (Table 4) and depends in part upon

Table 4. Removal of Representative Infectious Agents by Conventional Wastewater Treatment[17]

Infectious Agent	Primary Treatment % Removed	Secondary Treatment, % Removed	
		Activated Sludge	Trickling Filter
Salmonella	15	90-99	90-99.9
Mycobacterium	40-60	5-90	70-99
Shigella	15	80-90	85-99
Amoebic Cysts	Limited	Limited	10-99.9
Helminth Ova	70-95	Limited	60-75
Viruses	Limited	75-99	0-85

the nature of the infectious agent.[17] Primary sedimentation may remove up to 50 percent of the bacterial population, including pathogenic bacteria; in raw domestic wastewater. Although there is insufficient information, it would appear that because of a higher specific gravity, helminth ova are more effectively removed by sedimentation than amoebic cysts. Only a small percentage of the enteric viruses present in raw domestic wastewater appear to be removed by primary treatment. However, viruses are known to adsorb to particulate matter and probably occur as individual particles only on rare occasions. Viruses may also be embedded in particulate matter. For these reasons, there is reason to suspect that virus removal by sedimentation has not been accurately measured and, as a result, more viruses may be removed than the existing data would indicate. The same thought might also apply to other infectious agents.

As with primary treatment, the removal of infectious agents by secondary treatment, i.e., activated sludge or trickling filter followed by final clarification, is variable. Removal of bacteria may amount to as much as

90 percent. Amoebic cysts and helminth ova appear to be much more effectively removed by trickling filter treatment than by activated sludge. Of these two secondary biological processes, activated sludge appears to achieve the greatest and most consistent removal of viruses. It should be noted that numerous microorganisms, including bacteria, fungi, and algae grow in biological wastewater treatment processes and some of these may be present in the effluent. Very little is known about the health significance of these microorganisms or their products, or their subsequent fate in treatment processes which might be used in the potable reuse of water.

From Table 4 and the above brief discussion it is obvious that conventional wastewater treatment, consisting of primary and secondary treatment, reduces the density of infectious agents in wastewater but does not produce an effluent which is free of infectious agents. On the contrary, there may be a significant number of viable infectious agents in secondary effluent. The microbiological quality of a secondary effluent may be further improved, however, through disinfection. Depending on the pH and the turbidity of the effluent, a total chlorine residual of 2 mg/ℓ may achieve a 3 log reduction in coliform bacteria after a contact time of 30 to 60 minutes.[18] The enteric bacterial infectious agents are believed to have the same degree of sensitivity to chlorine as coliforms and could, therefore, be inactivated to the same extent. It has also been observed that an applied chlorine dose of 5 mg/ℓ to a secondary effluent and a contact time of 30 minutes may effect a 4 log reduction in the bacterial population.[19] Although data are lacking, it may be assumed that protozoan cysts and helminth ova, because of their general resistance to disinfection, would be ineffectively inactivated by chlorination of a secondary effluent as currently practiced. Further, certain enteric viruses appear to be more resistant to chlorine than the coliforms and perhaps other bacteria. To achieve a 3 to 4 log inactivation of viruses in secondary effluent with a contact time of 30 to 60 minutes, a total chlorine residual of 4 to 10 mg/ℓ and a low turbidity would seem to be required. Ozonation of a secondary effluent can also be effective in inactivating infectious agents, giving results equal to or better than chlorination. In designing any disinfection system, however, it is important to consider the inadvertent formation of toxic by-products.

The treatment of secondary effluent by processes more commonly associated with water purification can further reduce the density of infectious agents. These processes might include: chemical coagulation, filtration, activated carbon adsorption, and disinfection. Chemical coagulation-flocculation, particularly with lime at high pH, followed by clarification appears to be highly effective in removing enteric bacteria and viruses.[20] The use of either alum or ferric salts as coagulants may achieve up to 2 logs removal of bacteria and viruses. If sufficient lime is added to produce a pH greater than 11.0, microbial inactivation results in addition to removal. Enteric bacteria and viruses may be reduced by 3 to 5 logs by lime treatment of the water. Although no data seem to be available for high pH treatment, it would be reasonable to assume that protozoan cysts and helminth ova and other stages in the life cycle of these parasites would also be removed from water by such treatment followed by clarification.

Rapid sand filtration by itself is not effective in removing viruses and perhaps bacteria. However, if preceded by chemical coagulation followed by clarification, rapid sand filtration is effective, i.e., 2 logs or more removal of bacteria and viruses.[20] In fact, removals seem to increase as the filter becomes impregnated with carry-over floc. In this sense, it seems desirable to consider coagulation-flocculation and sedimentation followed by sand filtration as one process. Mixed-media filtration with polymer addition can also achieve up to 2 logs removal of viruses.[19] Porous media filtration, following coagulation and/or the addition of polymer, also appears to be effective in removing protozoan cysts, including *Giardia* cysts, and helminth ova. It should be recognized that filtration, in addition to removing infectious agents, accomplishes turbidity removal which is essential for effective disinfection.

Activated carbon adsorption may accomplish up to 2 logs or more removal of viruses.[20] In fact, removal may be as great as 5 logs under optimum conditions. On the other hand, bacterial growth may occur in activated carbon units with the result that the effluent may show a higher bacterial count than the applied or influent water. The removal of protozoan cysts and helminth ova by activated carbon does not appear to have been studied.

The final step of treatment in any water reclamation scheme will be terminal disinfection. Based upon existing information, experience and other considerations, the disinfectants of choice are either chlorine and/or ozone; another possibility is chlorine dioxide. In the case of chlorine, the efficacy of microbial inactivation is a function of the nature of the water, e.g., ammonia, the organism in question as well as the concentration of chlorine and exposure time, the pH of the water as it affects the predominant species of chlorine, and the temperature and turbidity of the water. Given the proper conditions, breakpoint or free residual chlorination (0.5 mg/ℓ for 60 minutes contact) has been reported to achieve a virus reduction of up to 5 to 7 logs.[21] The reduction of coliform organisms, and presumably the pathogenic bacteria, would be similar under the same conditions. Although there is limited information available, protozoan cysts and helminth ova have been shown to be more resistant to chlorine than bacteria and viruses. However, a 2 mg/ℓ free chlorine residual for 15 minutes at pH 6.0 has been observed to effect a 3 log reduction in the excystment of *Entamoeba histolytica* cysts.[22] The effectiveness of ozone in inactivating bacteria and viruses is equal to or perhaps better than chlorine. For example, it is possible to achieve a 5 log or greater reduction in viruses with an ozone dosage as low as 6 mg/ℓ and a contact time of 5 to 10 minutes. There does not appear to be any information available on the inactivation of helminths by ozone and that which is available on protozoan cysts is limited. Existing information would indicate that chlorine dioxide may be just as effective in inactivating enteric bacteria and viruses as chlorine. Data appear to be lacking on the efficacy of chlorine dioxide for the inactivation of protozoan cysts and helminths.

Although considerable data on disinfection have been generated, the theoretical foundation for understanding disinfection performance is inadequate. The efficacy of disinfectants and many of the decisions made in process design and operation are highly dependent upon this information. The traditional disinfection models of Chick and Chick/Watson (1908) are most often used but these do not adequately model disinfection performance. The current disinfection models are particularly deficient in the case of long contact periods.

Anticipating that there would be areas of acute water shortage in South Africa in the future, the National Institute for Water Research of South Africa initiated an aggressive water reclamation research program in the early 1960's. This research program included laboratory studies as well as pilot and full scale treatment plant investigations of various reclamation unit processes. As a result, a vast amount of information has been collected on the removal and/or inactivation of infectious agents in secondary wastewater effluent by chemical coagulation-flocculation, filtration, activated carbon adsorption, disinfection, and other treatment processes. This information has been summarized by the National Institute for Water Research and is given in Table 5.[21]

To supplement and thereby amplify the above, it would seem appropriate to consider the removal and/or inactivation of infectious agents as observed in several operating water reclamation plants. A review of the operational performance of these treatment plants would indicate that from a microbiological point of view, major attention has been given to the removal and/or inactivation of enteric bacteria and viruses; in most cases, the protozoan cysts and helminths have not been considered.

One of the first experimental water reclamation plants was at Windhoek, South Africa; this plant was commissioned in 1968.[21] The wastewater treatment portion of the plant consisted of primary sedimentation, trickling

Table 5. Reduction of Fecal Coliform and Viruses by Various Reclamation Unit Processes[21]

	Log Reduction*	
Unit Processes	Fecal Coliforms	Virus
Coagulation - Al_2SO_4 or $FeCl_3$	1-2	1-2
Lime Treatment, pH 11.2	2	3-4
Lime Treatment, pH 11.5	>5	4-5
Activated Carbon Adsorption	<0.5	5
Rapid Sand Filtration	1-2	1-2
Chlorination, <Breakpoint	1	1
Chlorination, >Breakpoint, low turbidity and nitrogen	>7	>7

*Results assumed to be achievable under favorable operating conditions filters, secondary settling, and maturation or stabilization ponds with 7 days detention. The effluent from the ponds was then treated by an integrated advanced wastewater purification plant, consisting of alum flocculation-flotation, foam fractionation, secondary lime-alum flocculation, sand filtration, breakpoint chlorination, activated carbon treatment, and terminal chlorination. Based upon observations made during the continuous inoculation of poliovirus, it was concluded that conventional secondary wastewater treatment (trickling filter or activated sludge) may be expected to achieve at least a 1 to 2 log reduction of viruses.[23] If the secondary effluent was subsequently treated by stabilization ponds, the viral density may be reduced another 3 logs. The direct treatment of humus (sedimentation) tank effluent by lime coagulation at pH 11.3-11.5, followed by sedimentation, could be expected to produce a 4 to 5 log reduction of viruses. Activated carbon adsorption may also achieve a 5 log reduction in viruses. Breakpoing chlorination appeared capable of accomplishing a 7 log reduction of the poliovirus strain tested.

In 1970, the experimental 4500 m^3/d Stander Water Reclamation Plant in Pretoria, South Africa, was commissioned.[21] Based upon the results achieved at this experimental plant, the Windhoek facility was modified. The Stander plant now treats secondary effluent by a sequence of processes including high lime treatment, clarification with ferric chloride plus polymer, ammonia stripping, primary chlorination, recarbonation, secondary clarification with ferric chloride plus polymer, pH adjustment, sand filtration, either breakpoint chlorination or ozone disinfection, two-stage activated carbon adsorption, and post chlorination.[24] An equalization basin is included following the initial clarification stage which utilizes ferric chloride and polymer. Fluctuation in the quality of the secondary effluent is attenuated by the equalization basin and was found to increase the reliability of the subsequent unit treatment processes. The Windhoek facility incorporates the same sequence of treatment units except that it has no equalization basin or facility for ozonation. Further, the Windhoek plant continues to treat maturation pond effluent while the Stander plant treats trickling filter or activated sludge effluent.[24] The microbiological quality of the water produced by both reclamation plants after various degrees of treatment and the final product water has been extensively monitored. No enteric viruses were detected, using two different concentration procedures, in 286 samples representing a volume of 1788 liters (152 ten-liter samples and 134 two-liter samples) taken after the final four treatment stages of the Windhoek plant and 461 samples representing a volume of 4610 liters (461 ten-liter samples) obtained following the last three treatment units in the Stander plant.[24] Many more samples were taken for determining the density of total bacteria, total coliforms, fecal coliforms, enterococci, *Clostridium perfringens*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Escherichia coli* B coliphage. The investigators concluded that for routine monitoring of the microbiological quality of water produced by reclamation plants, the following standards should prove sufficient: total bacterial plate count, 100/mℓ; total coliforms, 0/100 mℓ; enteric viruses, 0/10 ℓ; and coliphage, 0/10 mℓ. The use of acid-fast bacteria as an indicator group for assessing the microbiological quality of reclaimed wastewater has also been evaluated.[25] Acid-fast bacteria were found to be exceptionally resistant to most treatment processes; it was concluded that their absence after chlorination insured the absence of vegetative bacteria and enteric viruses. The total plate count was found to be a highly sensitive indicator of any microbiological contamination and the coliphage test, a rapid, economical, and simple method for screening removal and/or inactivation of viruses. After considering all available data, it was concluded that a total plate count of less than 100/mℓ and the absence of acid-fast bacteria, P. *aeruginosa*, total coliforms and coliphage in 100 mℓ of the final water are feasible parameters with a wide safety margin for the routine monitoring of the microbiological quality of water produced by reclamation plants.[25] Monitoring for parasitic ova has also been performed at both the Windhoek and the Stander reclamation plants by direct microscopic examination of 10 liters of membrane filtered concentrate.[26] No parasitic ova were detected in the final product water. It would appear that these infectious agents were effectively removed by sedimentation and filtration processes. Beginning in 1968, reclaimed wastewater from the Windhoek reclamation plant has been used for various periods of time to directly augment the normal potable water supply of the City of Windhoek. As a result, an epidemiological program of surveillance has been performed to detect the occurrence of communicable diseases caused by such organisms as *Salmonella*, *Shigella*, enteropathogenic E. *coli*, *Vibrio*, enterovirus and *Shistosoma*, as well as diseases such as viral hepatitis, meningitis, encephalitis, and non-bacterial gastroenteritis. As of 1978, it was reported that there has never been any transmission of these diseases associated with the reclaimed water.[26]

The EPA performed an 18-month wastewater treatment study at its Blue Plains Pilot Plant, Washington, D.C., to obtain data on the safety of the effluent for discharge upstream of drinking water intakes and for potential domestic reuse purposes.[27] Using Washington, D.C. degritted wastewater, the experimental treatment sequence was screening, lime clarification (pH 10.0), biological nitrification and denitrification, activated carbon adsorption, dual media filtration with alum and polymer, and disinfection (designed for 1 mg/ℓ free available chlorine with 20 minutes contact). Samples for determining enteric viruses were processed during three different periods of operation. The density of viruses in the raw wastewater ranged from 1850 to 18,000 pfu/100 liters in the samples taken during the three sampling periods. Viruses could not be detected following filtration during the first sampling period, in the effluent from the biological nitrification unit during the second sampling period, or following chlorination in the samples taken during all three sampling periods. During the entire 18-month study period, the average concentration of free available chlorine in the final effluent was 2.23 mg/ℓ (arithmetic mean of 57 determinations). The arithmetic mean density of total coliforms (114 samples), fecal coliforms (119 samples), *Pseudomonas aeruginosa* (36 samples), *Salmonella* (40 samples), and total bacteria plate count (44 samples) following terminal chlorination was 0.11, 0.17, 0.81, 0, and 66.8/100 mℓ, respectively.[27]

Water Factory 21, which has been in operation in Orange County, CA, since 1976, is an advanced wastewater treatment plant designed to reclaim unchlorinated secondary wastewater effluent for use as injection water for a seawater-barrier system or perhaps to augment domestic water supplies.[28,29] During one period of operation, unchlorinated trickling filter effluent was treated by lime clarification (pH 11.3), ammonia stripping, recarbonation, mixed-media filtration, activated carbon adsorption, and post-chlorination. Breakpoint chlorination for nitrogen control was also evaluated at different locations in the treatment sequence. During this period of operation, the geometric mean density of total coliforms and fecal coliforms in the unchlorinated trickling filter effluent was 89×10^6 and 25×10^6 MPN/100 mℓ, respectively. The reduction in total and fecal coliform bacteria by lime clarification was greater than 5 logs. It was also found that the lime clarification stage resulted in a 98 to 99.9 percent reduction in viruses, depending upon the virus detection procedure used. Based upon unconfirmed virus analysis, 48 trickling filter effluent samples out of 77 were found to be positive for viruses; the density, calculated as the geometric mean of the positive samples, was 1.1 pfu/ℓ. Over 25 different enteric virus types were identified in the trickling filter effluent. Of 77 chlorinated final effluent samples assayed, two samples were positive for viruses. The cause of both positive samples was believed due to the presence of a high concentration of activated-carbon fines in the samples which probably interfered with proper post-disinfection. In another period of operation, a high-quality activated sludge effluent was used as the influent to the advanced wastewater plant which consisted of lime clarification, air stripping without forced circulation, recarbonation, prechlorination, mixed-media filtration, activated carbon adsorption, and final chlorination; reverse osmosis following activated carbon adsorption was also evaluated. The geometric mean density of total coliforms, fecal coliforms, and viruses in the activated sludge effluent during this period of study was 1.6×10^6 MPN/100 mℓ, 0.55×10^6 MPN/100 mℓ, and 0.13 MPNCU/ℓ, respectively. The virus detection procedure used in this period of study was judged to be about three times more sensitive than that used in the earlier study with trickling filter effluent. Again, lime clarification removed more than 5 logs of the total coliform and fecal coliform bacteria. Following post-chlorination, the geometric mean density of total coliforms and fecal coliforms was 0.05 and <1 MPN/100 mℓ, respectively; no viruses were detected in the final effluent, i.e., following post-chlorination.

OTHER CONSIDERATIONS

Potentially, a variety of different infectious agents may reach a community's sewer system and be present in a raw domestic wastewater, e.g., infectious yeasts and molds and rickettsia. It would appear that these and perhaps others of possible health significance have been neglected with respect to their presence in wastewater and water supplies.

Another group of infectious agents, which appear to have been overlooked insofar as the water environment is concerned, is the "viroids." This term was first used to describe the infectious agent associated with "spindle tuber condition" in potatoes and was selected to indicate that the agent was similar to virus particles but had basic differences. The distinctive features of viroids are their nucleic acids, which are much smaller than those of viruses and their lack of protein coats. Admittedly, there is no known human disease transmissible by water which is caused by a viroid, sometimes referred to as a slow-virus because of the long incubation period required before onset of clinical symptoms. On the other hand, vigilance is required to determine the significance of these and perhaps other potentially infectious agents in water.

The presence and significance of antibiotic resistant bacteria in the water environment also need further attention. This phenomenon is associated with resistance (R) factors which are nucleic acid elements capable of rapid transfer by conjugation among gram-negative bacteria. R factors are known to increase the resistance of the host cells to various antimicrobial drugs and other antibacterial effects, such as heavy metals, UV light, phages, etc.[30] A high number of coliform bacteria, carrying R factors, have been observed in wastewater effluents and natural waters. This would indicate that R factors may be transmitted among bacteria in the water environment and, as a result, that R+ bacteria may be spread by water, unless removed or destroyed by effective treatment.[31]

Among the substances of potential physiologic concern that might be present in wastewater are the microbial toxins. Microbial toxins that can produce a physiologic response upon ingestion have been associated with *Escherichia*, *Vibrio*, *Clostridium*, and *Staphylococcus* species, among others. The production of exotoxins could be associated with the carry-over of excessive amounts of organic suspended solids from biological wastewater treatment processes and the subsequent decomposition of these materials by anaerobic bacteria in water storage tanks. Methods for the detection of microbial toxins in drinking water should be developed. Bacterial endotoxins, as measured by the Limulus Amoebocyte Lysate test, do not appear to have any health significance but the use of this test to monitor treatment processes should be evaluated.[32]

DEVELOPMENT OF MICROBIOLOGICAL STANDARDS AND CRITERIA

To ensure the microbiological acceptability of a water supply, standards or some form of criteria have to be applied. Heretofore, it has been common practice to develop a public water supply utilizing the highest quality water source available and for the most part, this has tended to minimize the risk of infectious disease transmission. Currently, a water to be potable must meet a MCL for coliform bacteria which is applied regardless of whether the source water has been indirectly impacted by wastewater discharges or not. Even with source waters of reasonably good quality, there have been instances where the existing MCL has not been 100 percent effective in protecting the public against waterborne disease. Where a source water of poor microbiological quality is to be used, such as with potable reuse, there is no question but that more rigorous quality standards and criteria are required. It is generally agreed that there should be no detectable pathogenic agents in water intended for human consumption.

Criteria and standards need to be related to particular points in the overall system and monitoring of these points is necessary to assure that the standards are maintained. The obvious points of monitoring for a direct potable water reuse system are: (1) the wastewater treatment plant effluent or water treatment plant influent, (2) treated water, and (3) the water distribution system. Real-time monitoring of the treated water before it is pumped into the water distribution system should be evaluated in detail. Monitoring of the water distribution system should cover all areas of the system and should be sufficiently frequent to provide a reasonable probability of determining the occurrence of infectious agents.

In the case of potable reuse, there does not appear to be any major advantage to be gained by substituting the fecal coliform test for the total coliform test as an indicator system. That total coliforms exist in greater number than fecal coliforms in wastewater provides an additional margin of safety. The current MCL for potable water based upon the total coliform test is not adequate with reclaimed water; with potable reuse, perhaps there should be a complete absence of total coliform bacteria in one liter or larger samples.

Further, coliform bacteria may be an adequate indicator for *Salmonella* and *Shigella* but perhaps not for all bacterial and other infectious agents that might be present in domestic wastewater. The possibility of other infectious agents must be considered with potable reuse and, in this case, perhaps a new indicator system(s) identified. For example, the Standard

Plate Count might be useful as a supplement to the total coliform test in monitoring the general bacterial quality of the product water and assessment of disinfection efficiency.

In considering a virus standard for reclaimed drinking water, a WHO Scientific Group "concluded that no viruses should be detectable in samples of between 100 and 1000 liters."[15] Since there remains a need for a better understanding of the reliability, limit of detection and precision of the current methods used for virus enumeration, there does not seem to be any way at the present time to establish a meaningful virus standard. If a virus standard could be established based on today's detection methods, there would still be problems in applying the methods to routine real-time monitoring, i.e., a minimum two-week period is required before a sample of water can be reported as negative for enteric viruses. It would seem reasonable, therefore, to identify a suitable indicator system for assessing the viral quality of a potable water.

There is currently no standard procedure for the detection and enumeration of intestinal protozoan cysts or helminths in water. Consequently, it is not feasible at the present time to consider the establishment of a standard for either protozoan cysts or helminths. A reliable procedure for their direct detection in water should be developed and/or a reliable indicator system should be identified. The relationship between coliform bacteria and the presence or absence of infectious parasites in water is currently unknown.

It would seem desirable to consider the development of MCL values for the potable reuse of water together with the establishment of criteria based upon the removal and/or inactivation of infectious agents and indicators of infectious agents achieved through water treatment. A great deal of knowledge is available on the removal and/or inactivation of infectious agents by various wastewater and water treatment processes. However, additional information is needed before treatment criteria can be established which will consistently produce a product water of acceptable microbiological quality. Further, the development of treatment criteria, with necessary safeguards, is dependent upon having sensitive and reliable detection methods for the various infectious agents of significance, i.e., bacteria, viruses, protozoa, and helminths. Included in this approach is the need to have appropriate indicator systems which can rapidly, reliably and with an acceptable degree of sensitivity, continuously monitor the microbiological quality of the product water. Questions regarding the possible presence of other infectious agents, e.g., infectious yeasts and molds, rickettsia, and viroids, and of toxins, and the transfer of R factors, must also be addressed.

The microbial flora of water distribution systems is very poorly characterized at the present time. Bacteria, fungi, and algae are present in some systems and probably contribute to the chlorine demand and to the presence of trace amounts of organic substances in the water. Standards related to microbial growth in distribution systems have not been instituted to date but the necessity for the development of such standards with water reuse systems should be considered.

SUMMARY AND CONCLUSIONS

Public officials have been concerned about biological contaminants in drinking water for over 100 years because of the potential for widespread waterborne disease. In using a contaminated source water such as with wastewater, proposals for direct potable reuse require a complete re-evaluation of the means for biological control. Since it is generally agreed that there should be no detectable pathogenic agents in water intended for human consumption, biological issues must continue to be a principal concern in criteria development.

A wide range of infectious agents may be found in raw domestic wastewaters. The more usual infectious agents may be classified within four broad groups: bacteria, viruses, protozoa, and helminths. That these infectious agents, derived principally from infected persons and found in a raw domestic wastewater, may be spread to others via the water route is unquestionable. Other agents of concern include toxins, antibiotic resistant bacteria, fungi and possibly viroids. Although some infectious agents cannot survive outside their host for any great length of time, their environmental transmission is normally controlled through wastewater and water treatment.

Acceptance of a water, for most purposes, requires that criteria or standards be established with respect to its microbiological quality. In the case of reclaimed water for potable reuse, the criteria or standards may be based upon specific infectious agents, appropriate indicator system(s), and/or required treatment. A criterion or standard based upon each specific infectious agent is impractical because of the different types and densities that might be present, which in turn would require a large number of different tests. Further, the current detection and enumeration methods for viruses, protozoa, helminth, and some bacteria are inadequate. The indicator organism approach is practical and is currently being used in the case of coliform organisms; in fact, the MCL for the microbiological quality of drinking water is currently based solely upon coliform bacteria. In view of the available data base, the coliform test is adequate as an indicator of the infectious enteric bacteria and perhaps other infectious agents when a high quality raw water source is used for a water supply. However, in the case of reclaimed water for potable use, the current coliform test alone is inadequate for assessing the viral quality of the water and its adequacy for indicating the presence or absence of some pathogenic bacteria, infectious protozoa, and helminths is uncertain. Studies on the reliability of the coliform bacteria as an acceptable indicator are needed, particularly with respect to assessing the microbiological quality of reclaimed water for potable reuse. Further, other indicator systems such as coliphage, acid-fast bacteria, and the Standard Plate Count, should be studied as potential indicators of the different infectious agents that might be found in water. In this respect, no single indicator system may be adequate; thus, several indicators may have to be used to properly and reliably assess the microbiological quality of a reclaimed water.

Although today's technology appears capable of providing the degree of treatment required to meet any microbiological criteria associated with the reuse of water, this does not eliminate the need for additional confirmatory data nor the need to insure the operational integrity of treatment systems. In this respect, reliable monitoring techniques must be available and rigorously employed.

Better information on disinfection is needed. Although disinfection is the process most relied upon for protection against pathogens, there are gaps in the existing knowledge, particularly as applied to reclaimed water. Better data are necessary for comparison of disinfectants and for validation of the disinfection models using microorganisms typically found in wastewater and under conditions of concentration and time comparable to full-scale treatment. A comprehensive characterization of pathogens in wastewater at several sites is an essential part of the microbiological assessment of reuse. A great deal more laboratory and field data using pilot and large scale treatment plants are required.

Methods for the detection and enumeration of viruses, protozoa, helminths, and some bacteria in water are inadequate or nonexistent. Suitable analytical methods, including sampling considerations, need to be developed and evaluated in order to allow thorough microbial characterization of direct potable reuse processes throughout the treatment train. The latter studies must include a rigorous microbial monitoring program for various infectious agents together with different indicator systems so that the relationships between appropriate groups can be established. The derivation of drinking water directly from treated wastewater or other heavily contaminated source waters should ideally require the use of real-time indicators. The occurrence of an unacceptable level of the indicator(s) in the final product will require that the water in question be subjected to additional treatment.

It is known at the current time that microbial inhabitants of some water distribution systems contribute to the deterioration of the quality of the water in the system and of the system itself. Exactly which bacteria, algae, and fungi are active in water distribution systems and the extent of their activities are not known. Further, it appears that many of the bacterial inhabitants of water have not been cultured or identified. Some may be pathogenic or produce toxic products or other products which become toxic after reaction with disinfectants such as chlorine. These problems may be exacerbated by the accumulation of organic matter and other microbial nutrients in direct potable water reuse systems. In addition, direct potable reuse within a single community, as contrasted with reuse of one community's wastewater by another, introduces the possibility of cyclic effects. This aspect should be studied as it might impact the microbiology of wastewater, wastewater treatment processes, water treatment processes, and water distribution systems.

Finally, the microbiological safety of potable water impacted directly by wastewater must ultimately be confirmed by epidemiological studies. To be useful in evaluating hyper-endemic transmission of microbial disease, these studies must be carefully designed and performed. Recent studies have demonstrated such an application of an epidemiological investigation and a similar approach should be applied to the health concerns of potable reuse.

RECOMMENDATIONS FOR RESEARCH

The lack of specific information regarding infectious agents in water on which to evaluate risks to health associated with the potable reuse of water has been highlighted in the paper. Emphasis was placed on the need to develop additional information in areas such as analytical methods for indicator organisms and specific pathogens, monitoring techniques, disinfection models, and the survival or regrowth potential of various infectious agents in water. Specific research needs are outlined below.

1. Methods for the detection, enumeration and identification of many important pathogenic microorganisms are inadequate to allow thorough microbial characterization of direct potable water reuse processes throughout the treatment train or to evaluate their adequacy. Research is needed to:
    a. Identify and compile appropriate existing quantitative methodology, and

b. Develop and evaluate appropriate quantitative methodology for those organisms or groups of organisms for which such methodology is not currently available.

2. Evaluation of the appropriateness of the conventional indicator systems, and possibly develop new systems in order to determine the microbial safety of reclaimed water for potable purposes is required. The indicato system(s) must be able to evaluate the presence of pathogenic microorganisms and/or toxic products of microbial origin that may be in the source and finished water. Ideally the indicator system should also be able to demonstrate efficacy of the treatment train or other systems must be developed for this purpose. Desirably, the indicator systems should provide data rapidly (less than 24 hours) or be capable of automation.

3. Characterization of raw water quality is required in terms of the occurrence of infectious agents, toxins, and antibiotic resistant organisms that must be removed by the reuse water treatment train. These investigations should be integrated to establish the prevalence of known waterborne fungi, bacteria, virus, protozoa, and helminths in effluents from various treatment processes; the pathogens of most frequent occurrence should be determined and correlated with conventional (existing) or non-conventional (new) indicator systems. Once the important microbiological agents are identified, it will be necessary to determine the required frequency of analysis so as to gather sufficient baseline data on unsatisfactory trends in the source water and the impact on individual barriers in the treatment train. This information should then be used to establish monitoring patterns.

4. Comparison of direct microscopic counts of bacteria in water with counts derived from culture techniques suggests that only a small fraction of the bacteria in water have been cultured and identified. Some

of the unknown bacteria may be opportunistic pathogens or produce toxic by-products. Development of new culture methods which can be used for growth and characterization of the unidentified bacteria are needed, as are surveys of the flora of existing water distribution systems. Attention should be given to the production of toxins by microorganisms isolated from distribution systems and whether various pathogenic strains remain virulent.

5. Studies are required to develop methods so as to characterize biological wastewater treatment processes (usually measured only as volatile suspended solids) from which microorganisms could be carried over and cause serious interference in water treatment processes. Such interferences might include: (1) excessive disinfectant or coagulant demand, (2) production of toxins during anaerobic decomposition of organic matter deposited in holding tanks or sedimentation basins, (3) slime growths in porous media filters, and (4) production of excessive amounts of organic matter which may penetrate the entire sequence of the treatment train.

6. Determine the survival and regrowth potential of pathogenic microorganisms and correlate this information with indicators identified as being meaningful with water reuse systems.

7. Reliable monitoring techniques for ensuring the operational integrity of treatment systems will require the development of techniques for selected infectious agents and indicators of treatment effectiveness. To ensure the attainment of meaningful information, appropriate analytical techniques must be evaluated for reliability and realistic sample

volumes must be established to optimize detection. Appropriate monitoring sites need to be identified within the treatment train together with frequency of sampling related to treatment process variations, uniformity of the product water and integrity of the distribution network. A realistic goal of this research would be to develop real-time monitoring capability for infectious agents and/or appropriate indicators.

8. Although much disinfection data has been collected, the theoretical foundation for understanding disinfection performance is inadequate. The efficacy of disinfectants and many of the decisions made in process design and operation are highly dependent on this understanding. Research is needed to:

a. Generate data, using standard methodology, that permits a direct comparison of the efficacy of different disinfectants on each of the several classes of infectious agents of concern. Information on concentration/time relationships, various residuals, interferences and undesirable by-product formation is required.

b. Develop realistic and useful disinfection models and field test them with reuse disinfection systems.

9. When all monitoring safeguards have been realized and reclaimed water is approved for consumption, the actual effect upon the health of the consuming population must be determined through epidemiological investigation. Epidemiological approaches for detecting relatively small increases in endemic levels of microbial infections from single sources such as drinking water have not been clearly established. Any

approach must be capable of detecting increased incidence over a background that normally exists from a variety of sources. Adequate control systems must be identified so that the true contribution from drinking water exposure can be determined. When such an investigative approach has been devised and determined to be feasible, it should be field-tested with populations that consume water produced from heavily contaminated source water.

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Work Group Report/Issues Paper

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SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS
OF THE WORK GROUP ON ENGINEERING ISSUES

SUMMARY

The Engineering Workshop wishes to congratulate EPA for its forward step as reflected in this meeting. We encourage EPA to move forward as rapidly as possible in this work.

At this Symposium on Potable Reuse, there are six workshops:

- Chemistry
- Engineering
- Groundwater Recharge
- Microbiology
- Non-Potable Options
- Toxicology

In undertaking the Engineering Issues, our work group is looking to the Chemistry, Microbiology, and Toxicology work groups for water quality goals which apply to reclaimed wastewater. We are looking to the Groundwater Recharge group for the improvements in water quality which occur in underground aquifers, and we are looking to the Non-Potable Options work group for other uses to which reclaimed wastewater may be put.

The Engineering Group has studied seven major engineering issues:

1. Quality of Source
2. Storage Prior to Treatment
3. Specification of Treatment Processes and Design Criteria
4. Process Redundancy Requirements
5. Parameters Affecting Plant Process Control and Operation; Types and Frequencies of Sampling and Monitoring for Plant Control
6. Storage of Treated Water Prior to Use (e.g., Recharge or Surface Reservoir)
7. Operation and Maintenance Criteria

A. Under "Quality of Source", we have considered:

1. Elimination of Industrial Discharges and Pretreatment
2. Quantifying Risk of Accidental Spills (Comparable to Surface Sources?)

3. Sampling Prior to Selection of Source
4. Maximum Allowable Variability of Selected Parameters

B. Under "Storage Prior to Advanced Treatment," we have evaluated:

1. Flow Equalization
2. Two or Three Basins with One to Two Days Residence Time
3. Monitoring of Each Basin - Sufficient Storage to Permit Rejection of Supply

C. Under "Specification of Treatment Processes and Design Criteria," we have considered:

1. Specifying Obligatory Processes or Design
2. Specifying Obligatory Combinations of Processes
3. Specifying Optional Processes or Groups of Components

D. Under "Process Redundancy Requirements," we have looked at:

1. Standby Units
2. Fail-Safe Power System
3. Provision for Alternative Discharge in Event of Power Failure
4. Specifying that Treated Wastewater Provide Only Fixed Percentage (say 30%) to Total Potable Use
5. Requiring Fault-Free Analysis - with a Specified Maximum Probability of Mechanical Failure

E. Under "Parameters," we have limited monitoring considerations to those tests which are needed for plant process control. In addition, we have considered the required types and frequencies of sampling and monitoring.

F. Under "Storage Prior to Use," the Engineering Group has looked at:

1. Minimum Residence Time In Storage
2. Groundwater Recharge
3. Means for Controlled Diversion in Event of Breakdown
4. Surface Reservoir Blending

G. And, finally, under "Operation and Maintenance Criteria," we have discussed:

1. Level of Operator Training
2. Maintenance Program Approved by Appropriate Agency
3. Data Reporting Requirements
4. Operation and Maintenance and Operator Training Manuals

CONCLUSIONS

Given that indirect reuse is a reality and that direct potable reuse is an impending possibility in this country, the Engineering Workshop agrees that one set of standards should be developed for water quality at the consumer's tap which will apply to all waters regardless of source.

The Engineering Group further agrees that:

- Treatment technology does not appear to be a limiting factor in the implementation of potable reuse.

- Because present drinking water standards are incomplete for polluted sources, potable reuse criteria and standards should include:

  - Monitoring of source quality
  - Frequency of monitoring will vary according to source quality
  - Determinations of limiting concentrations and provisions for acceptance or rejection of the water at various points in the treatment process as approved on a case-by-case basis.
  - Pilot plant studies to determine treatment and reliability requirements, prior to plant design.

- Maximum flexibility should be allowed for creative process designs which are cost effective and meet health requirements.

- Minimum qualifications should be developed for supervisory and operating personnel in potable reuse systems, and separate operator certification programs for a new class of operator should be examined.

- Owners should be provided with complete Operation and Maintenance and Operator Training Manuals prior to plant startup.

- Storage of treatment plant influent may be advantageous for flow equalization, blending, plant reliability, spill mitigation, or for other reasons.

- Adequate removal of microorganisms must be provided, but the methods of removal are project specific. Various processes are available to achieve this including: (1) removals in groundwater spreading, (2) coagulation, settling and filtration, (3) high pH treatment, and (4) disinfection.

- Processes for the adequate removal of organics are imperative and may include: (1) biological oxidation, (2) adsorption, (3) membrane processes (high molecular weight organics), (4) air stripping (volatile organics), and (5) coagulation.

- If certain inorganics and heavy metals must also be reduced in concentration, processes may include: (1) reverse osmosis, (2) ion exchange, (3) adsorption, (4) coagulation, (5) oxidation, (6) biological oxidation, and (7) filtration.

- A "mulitple barrier" treatment approach is advantageous in minimizing health risks.

- Good cost information for water renovation processes is available for evaluation of alternatives.

- Potable reuse facilities are manufacturing plants and should be designed to include provisions for rejecting the influent and for interrupting delivery of the product to the consumer.

- Properly protected storage shoudl be provided for treated water prior to use. The storage should be sufficient to provide lead time for monitoring. There should be means for controlled diversion in event of plant breakdown.

ENGINEERING RESEARCH NEEDS

- The Engineering Group feels that the most important research need is the health effects work necessary to establish drinking water standards applicable to reuse situations.

- Characterization of potential source waters for reuse
    - Select waters in areas of most likely potable reuse need
    - Give priority attention to study the most imminent need locations
    - Accomplish the physical, chemical and microbiological characterization at the source waters by using the limits of measurement technology as contrasted to measuring only drinking water MCLs and priority pollutants lists
    - Perform multiple samplings at certain locations to establish some indication of variability, frequencies of occurrence, and calculation ranges over time.

- Characterization of performance of representative water reuse systems
    - Bracket each unit process for limit of technology type list of physical, chemical, and microbial constituents
    - Provide multiple samplings to evaluate reliability.

- Re-evaluate chlorine-ammonia disinfection with respect to by-product formation under various initial mixing conditions, pH levels, contact times, efficacy, temperature and other factors.

- Need to identify and validate indicators of system performance for quality and process control.

The Engineering Group suggests that many of the recommendations from the 1975 Boulder Reuse Conference are still valid and merit implementation.

ENGINEERING ISSUES

by

Russell L. Culp*

INTRODUCTION & BACKGROUND

The Assignment

The purpose of this paper is to set forth for subsequent discussion the engineering issues involved in the development of criteria and standards for potable reuse of water derived from municipal wastewaters. In doing this, it will be impossible to separate completely the engineering issues from the other issues because they all are so closely interrelated. Further, it probably is not desirable or wise to do so. The main focus will be on the engineering issues, but other issues will be raised as they affect engineering considerations.

The Big Question and Some Corollaries

The first and principal question which arises is -- is it possible to develop criteria and standards for potable reuse which will adequately protect the public health? If it is assumed for the moment that this can be done, the next logical question is how good must the reclaimed water be? Must it be:

1. as good as existing public water supplies? or
2. better than present public water supplies? or
3. perfect? or
4. is the whole idea of drinking reclaimed wastewater so distasteful and repugnant that it should be rejected on this basis alone without further consideration?

Further, is there a need to recycle water for drinking and culinary use? Is it not possible to:

1. limit use of reclaimed water to other types of use and to exclude potable reuse, or
2. use bottled water for potable purposes, or
3. install dual public water supply systems?

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All of the questions posed above relate in some way to the costs of water recycling systems as well as to other engineering aspects. The required water quality and the exclusion of potable reuse for reclaimed water each have significant impacts on the feasibility of water recycling projects. The imposition of unnecessary quality and treatment requirements and particularly the prohibition against potable reuse can place such great economic burdens on proposed recycling projects as to cause their abandonment.

With the regard to the need for potable water reuse, one thing is certain, experience has shown that such projects cannot be developed until there is an absolute and readily demonstrated need for such a project and that there are no good alternatives. Successful potable reuse projects are born, not from choice, but, rather, solely out of necessity. The principal needs are in regions of groundwater mining and surface water shortage. In these locations in the future, the need for water recycling undoubtedly will increase.

The NIPDWR (National Interim Primary Drinking Water Regulation)

The present NIPDWR do not apply in their entirety to water derived from wastewater although many portions apply directly to reclaimed wastewater without change. They are based on the use of the best available source of supply, as have been all previous Federal drinking water standards. No national standards have ever been developed for reclaimed wastewater as a source of public water supply. There is a demand for such a separate set of standards, but there is even a greater demand for a set of standards which would apply to all public water supplies regardless of the source of supply utilized. There is some opposition to a single set of standards, which is based on the premise that all existing water works might be subjected to additional monitoring requirements which are needed to assure safety of reclaimed water but which are not needed for supplies from better sources. However, the existing NIPDWR already take into account the different treatment and monitoring needs of ground and surface water supplies, and it appears logical that similar differentiation could rather easily be extended to accommodate a new third source category.

The present NIPDWR do apply to some rather heavily polluted sources of surface water supply such as the Ohio, Mississippi, and Missouri Rivers. At times the proportion of wastewater in some existing approved sources of public water supply approaches or exceeds that which would prevail in sources for planned water recycling projects. For reuse projects, under most limiting conditions of chemical quality, it is not possible to recycle continuously more than about 33 percent of wastewater unless reverse osmosis or some other expensive demineralization process is provided[2,3,4].

If, at some time, a definite decision is reached that it is indeed impossible to develop a set of water quality standards which will properly protect public health when wastewater is intentionally recycled, then this immediately raises serious questions concerning the safety of existing polluted surface water sources. Will these existing supplies continue to be accepted as satisfactory, or will they be upgraded as a result of their observed resemblance to water reclaimed from wastewater which has been declared to be an unsafe source? Hopefully, they would be upgraded. If so, then at least one major benefit would result from consideration of quality standards for potable water reuse.

The Identity Problem - Forever Wastewater

Planned wastewater reuse suffers from an identity problem which is not associated with unintentional reuse. When wastewater is discharged to a surface water supply source or enters a well water aquifer, it loses its identity. It enters the surface stream as wastewater, but comes out as public water supply. Similarly, it enters the groundwater basin as wastewater, but is withdrawn as well water. In contrast, when wastewater is intentionally recycled to augment a source of supply -- regardless of the degree of wastewater treatment provided, or of the number and type of water purification processes employed, or even of the actual quality of the water produced -- it is tagged by the public as forever wastewater. For this reason, consideration should be given either to surface spreading or injection and storage in a groundwater basin, or to dilution by runoff and storage in a surface reservoir prior to withdrawal for reuse. In addition to better public acceptance, there are engineering advantages and public health benefits to either of these arrangements. Both provide dilution, storage, and separation of the discharge and withdrawal points. This gives time for sampling and testing of the water prior to use. It also provides time for natural bacterial die-away. For these and other reasons, these factors of time-in-storage, separation-in-space, and dilution are rather important public health measures to be included in all reuse projects.

Simulated Indirect Reuse

Intentional wastewater reuse schemes which include surface spreading or injection of the wastewater in a groundwater basin or dilution of the wastewater by surface runoff and storage in a lake or river impoundment prior to withdrawal for reuse are sometimes referred to as simulated indirect reuse. This is appropriate because of the similarity of the planned reuse schemes to the unintentional reuse which has taken place for many years in the Nation's major river systems which serve both as sources of public water supply and receiving waters for wastewater discharges. More general use of the term simulated indirect reuse may be helpful in providing better public understanding of the intentional reuse process by relating it to a long accepted practice.

Reliability and the Human Factor

The reliability of wastewater treatment operations is a matter which has been suspect for many years, and remains so at the present time. In the past 10 or 15 years tremendous strides have been made in the development of treatment processes, monitoring equipment, automatic testing apparatus, and in computer reporting and control. There is virtually no limit to the technological capability which can be applied to improve the safety and reliability of wastewater reclamation operations. However, the manner in which all of this fantastic paraphernalia actually operates depends upon the actions of one or more human beings. This human factor can either greatly enhance and strengthen, or completely destroy the reliability of the entire operation. The results obtained from the human link depends upon the attitudes, intentions, capabilities, and actions of the governing body, the manager, the supervisor, and the operator. If all the right conditions prevail simultaneously up and down this chain of human relations, then the operator can become the greatest asset of all to plant reliability. Once it is established that a certain process will produce a certain result, then he can provide anticipation, early detection, and correction of trouble even before it occurs, and long before it is reported to him in the form of alarms from the monitoring equipment. On the other hand, if the operator for any reason fails to properly respond either to the early warning signs, which only he can sense, or to the later obvious sights and sounds of the alarm signals, then the system will fail. Establishing the right conditions for proper continuous functioning of the human element is the most important single factor in assuring plant reliability, because human performance on the negative side is one of the ultimate limits to plant safety, whereas human performance on the positive side is one of the great unquantifiable assests to safety in times of emergency. Unfortunately, the quantification of human behavior is far less advanced than the quantification of mechanical failures.

Historically, water treatment operations have a reputation for being more reliable than wastewater treatment operations. Also, as described in more detail later, in seeking to meet higher reclaimed water quality requirements, it is generally more economical to increase the amount of water purification rather than the amount of wastewater treatment. For these two reasons and others, emphasis in recycling projects should be placed on the water treatment aspects.

The Moving Target

During the past 20 years, efforts to prefect a set of water quality standards for renovated wastewater have been delayed by a series of concerns. One of the first was bacteriological quality. This was followed by uncertainties about virus, TOC, and now by certain known and other unidentified trace organics. As water treatment technology was developed to solve each of these problems, some new problem immediately arose to take its place. Engineers and scientists who were attempting to develop standards were shooting at a moving target. Even now, detection limits for impurities in water are being extended from parts per trillion to identification of single molecules. Perhaps this development will open up a whole new series of concerns to be resolved before standards can be established or accepted.

On the other hand, it is more likely that there already is enough scientific and technical information available to allow a decision to be made on whether it is possible to now develop either a single set of water quality standards for potable water regardless of source, or a new, second set of standards for reclaimed wastewater intended for potable use. Another possible conclusion at this time might be that there is enough evidence that the idea using reclaimed wastewater for drinking should be dropped.

The Detailed Engineering Issues

The preceding discussion of some general background information is now to be followed by a presentation of some detailed data regarding engineering aspects of water quality criteria and standards development. This includes an attempt to define the engineering strategies and options for converting wastewater to potable water under conditions of: (1) once-through reuse, (2) repeated recycling, and (3) simulated indirect reuse. It discusses source control considerations and spill prevention and mitigation steps. It examines monitoring and process control and research and development needs. It also presents a summary of the engineering issues and suggests steps which might be taken to resolve engineering problems.

ENGINEERING STRATEGIES AND OPTIONS FOR CONVERTING WASTEWATER TO POTABLE WATER

Factors Affecting Water Reuse Decisions

There are a number of factors which affect water reuse decisions. These factors apply to all reuse projects, regardless of whether or not they include provisions for potable reuse. They include:

- Local conditions
  Necessity for water reuse
  Localized water demands and requirements
  Availability of fresh water resources and their potential to satisfy demands
  Location and elevation of points of reuse with respect to wastewater outfall
- Quality requirements for different beneficial uses
- Degree of contaminant removal obtained, and the reliability of liquid treatment processes
- Potential health risks
- Environmental issues

The first question is: is there a definite need for the project and will it find local acceptance? It is obvious that most water reuse projects are going to be developed in water-short areas of the country.

There is a rather large area in the Continental U.S. which has future requirements for water which exceed surface water flows even in an average year[1]. This area includes:

Southern California
Arizona
Southeastern Nevada
New Mexico
Colorado
Southeastern Wyoming, and
Northern Nebraska

There is an additional area in which future water needs exceed surface water flows in a dry year. This includes:

Nevada
Southeastern Oregon
Southern Nebraska
Western Kansas
Western Oklahoma, and
Western Texas (See Figure 1)

In addition to these areas of surface water shortages there are also regions of groundwater mining. Areas with more than 500 mgd (million gallons per day) of groundwater mining include:

Central California
Arizona
Extreme Eastern and Extreme Western New Mexico
Southern Nebraska
Western Kansas
Western Oklahoma, and
Central Texas

There are other areas where groundwater mining is between 1 and 500 mgd, including:

Eastern Washington
Oregon
Northern and Southern California
Idaho
Nevada
Western Utah
Montana
Wyoming
Colorado
Central New Mexico
Northern Nebraska
Southwestern North Dakota
South Dakota
East and West Texas
Western Iowa
Missouri
Arkansas
Louisiana
Western Mississippi
Eastern Georgia
Alabama
Florida
South Carolina
North Carolina
Virginia
Eastern West Virginia
Maryland
Eastern Pennsylvania
Southern New Jersey (See Figure 2)

There are specific locations within these areas of deficient surface water flows and mining of groundwater where water reuse should be considered.

Once a decision is made to consider water reuse, the next logical question is: for what purposes will water be reused? In this regard, it is helpful to look at national fresh water withdrawals from all sources of supply. These are shown in Table 1.

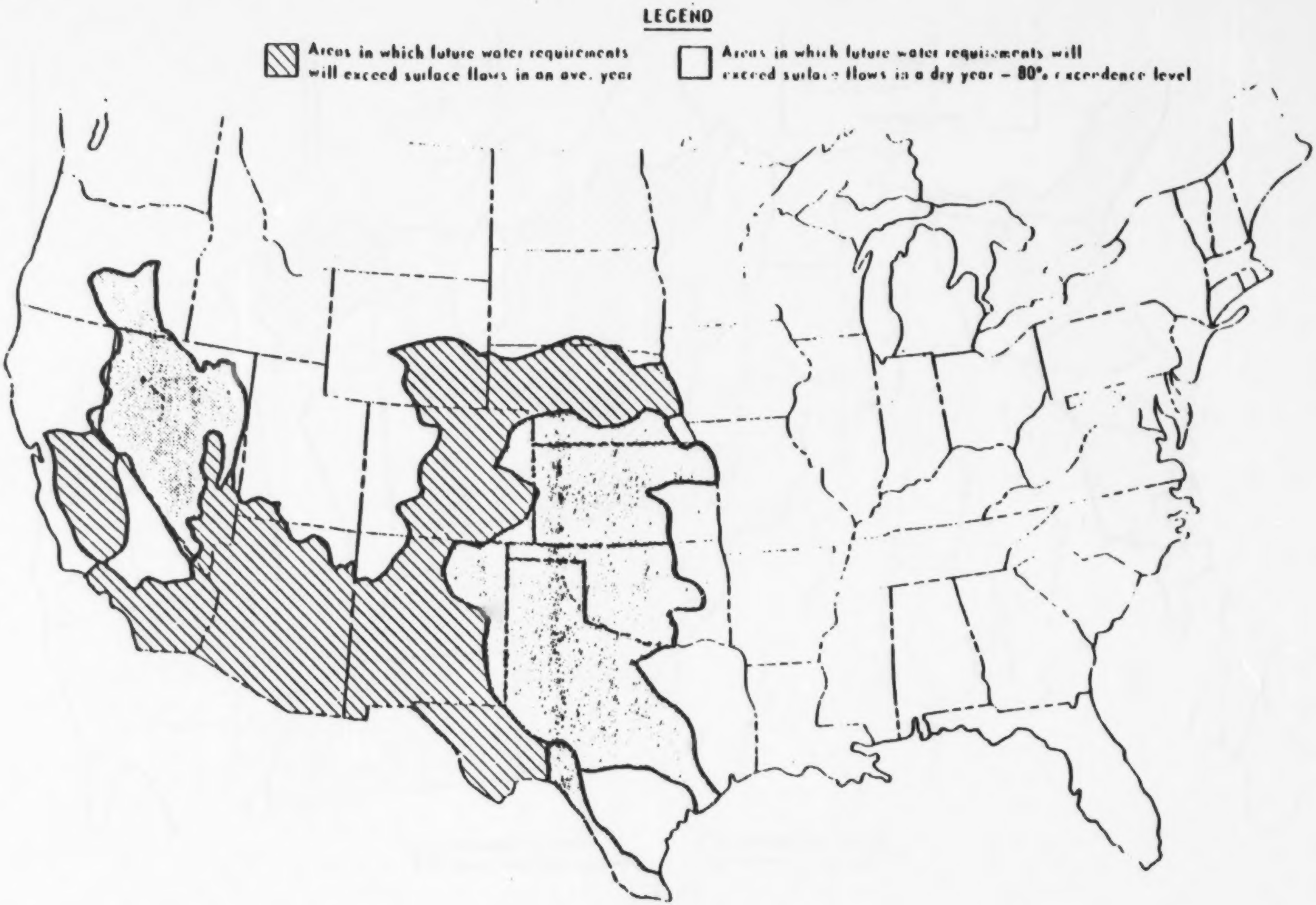
LEGEND
▨ Areas in which future water requirements will exceed surface flows in an ave. year
☐ Areas in which future water requirements will exceed surface flows in a dry year – 80% exceedence level

Figure 1.* Future Water Requirements Vs. Surface Water Flows

*From Reference (6).

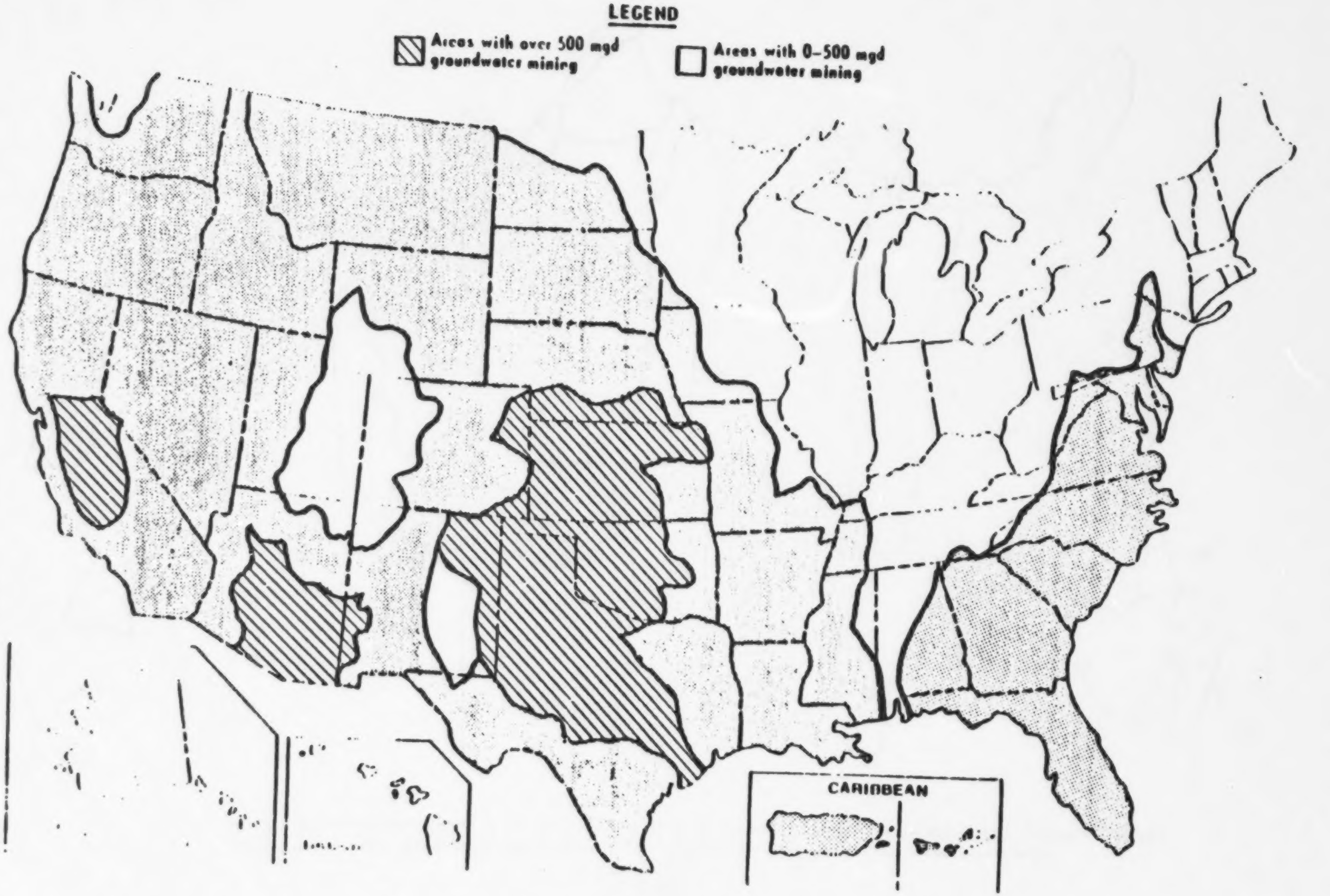
LEGEND
Areas with over 500 mgd groundwater mining
Areas with 0–500 mgd groundwater mining
CARIBBEAN

Figure 2.* Areas of Groundwater Mining

Fr efe e (

TABLE 1[1]. NATIONAL FRESH WATER WITHDRAWALS - 1975

Water use	1975 Use, thousands of mgd	Portion of total national use
Agricultural	185	51.5%
Steam electric power	89	24.5%
Manufacturing	51	14.0%
Domestic & commercial	29	7.5%
Minerals	7	2.0%
Public lands & fish hatcheries	2	0.5
TOTAL	363	100.0%

From Table 1[1] it is seen that 90 percent of total water use is for agricultural, steam electric power generation, and manufacturing. This is significant relative to water reuse, because wastewater receiving only secondary treatment will satisfy quality requirements for most of these uses except domestic reuse and certain manufacturing processes involving food and drink. Therefore, it would seem that water reclamation for potable reuse will always play a relatively small role in terms of total volume of water produced in the overall water supply picture. However, to many communities located in water short areas with no other means to augment their supply of water, the prospect of potable water reuse can be an extremely important matter.

General Strategies for Potable Water Reuse

Successive Reuse--

One of the major considerations in potable water reuse is the build-up of undesirable chemical constituents with successive cycles of reuse. This problem has been studied by several investigators[2,3,4]. The result of these studies which is of specific interest here is that, under most equilibrium conditions, the maximum allowable recycle rate is about 33 percent. At greater recycle rates, some demineralization system, such as reverse osmosis (R.O.), must be included in the train of treatment processes. Because the cost of R.O. with respect to the cost of other reclamation processes is so high, there is a substantial cost break between reuse treatment systems which include R.O. and those that do not. However, the inclusion of R.O. in a treatment system adds greatly to the overall reliability of the system because it provides a back-up process for filtration, adsorption, nitrogen removal, and other unit processes commonly used in water reclamation. Actually the principal difference between once through and successive reuse systems is that virtually all successive reuse systems include R.O. while once through systems may or may not depending upon the degree of reliability desired and other factors. Therefore, the matter of making cost comparisons can be simplified merely by adding or deducting the cost of R.O. to the total costs for the other unit processes.

Direct Once Through Reuse--

As mentioned earlier in this report, direct (or pipe-to-pipe) once through reuse may or may not be acceptable at the present state of the art. Rather, current stategy would be to simulate accepted practices now followed in the indirect reuse of wastewater which has taken place for many years.

Simulated Indirect Reuse--

This means that the treated wastewater to be renovated would be subjected to dilution and retention in storage, and that separation would be provided between points of wastewater discharge and withdrawal for subsequent water treatment. This can be done in either of two ways, that is by discharge of the treated wastewater to a groundwater reservoir or a surface water reservoir. In discharging to a groundwater reservoir either surface spreading or well injection may be employed.

Introduction into the reuse system of ground or surface storage in order to gain the benefits of natural purification processes presently used in indirect reuse means that a decision must be made regarding the location of certain treatment facilities. Is it cheaper to provide advanced wastewater treatment (AWT) ahead of the storage, followed by conventional water treatment? Or, is it more economical to provide only conventional secondary treatment ahead of storage, followed by advanced drinking water treatment (ADWT)? Fortunately these questions have been studied rather thoroughly and the results are presented in a report[5] to EPA. To obtain a given quality of finished water, it is more economical to provide only secondary treatment of wastewater prior to storage, followed by advanced drinking water treatment.

Groundwater Recharge--

The recharge of underground aquifers may be either direct or indirect. Direct recharge usually is by means of injection wells. Indirect recharge is often accomplished by surface spreading of treated wastewater. Whatever means of recharge is used, some dilution of the recharge water is provided by mixing with the groundwater contained in the aquifer, and some purification is provided by passage of the water through the granular water-bearing materials. In addition, in the case of surface spreading of wastewater, further purification of the wastewater may be provided by:

- percolation through the aerobic zone of soil,
- uptake of nitrogen, phosphorus, and other substances by crops or vegetation,
- filtration and adsorption in the soil overburden above the aquifer, and
- bacterial or chemical action.

The quantities of contaminants removed in surface spreading may be highly variable depending upon several factors including:

- the pretreatment provided,
- climate,
- type and depth of soils,
- hydrogeology of the aquifer,
- types and frequency of harvesting of crops and vegetation,
- the rate of application of wastewater, precipitation, and runoff waters, and the,
- rate of groundwater movement.

However, the removals obtained in surface spreading operations are usually sufficient in that the amount of pretreatment required for the wastewater is less than in the case of recharge by direct injection.

In virtually all cases, once the wastewater reaches and is mixed with the naturally occurring groundwater, the mixture must meet drinking water standards, or better.

Pre-Treatment Requirements for Waters Used in Groundwater Recharge by Surface Spreading or Well Injection

General--

In the past, and prior to the recent concern about trace organics in drinking water, several apparently successful surface spreading recharge projects were developed and operated using secondary effluent. Notable among these projects is one at Whittier Narrows, California.

Presently, in California, under Dept. of Health "Draft Groundwater Recharge Guidelines", water for surface spreading at new projects would have to be subjected to the following minimum treatment:

- source control of toxic industrial chemical compounds
- adequate oxidation
- carbon adsorption with 30 minutes contact
- percolation through an unsaturated aerobic zone of undisturbed or approved soil for a minimum distance of 10 feet
- dilution by equal quantity of groundwater
- one-year's storage

This is an interim standard subject to modification on a case-by-case basis. The establishment of permanent standards is awaiting the outcome of the Orange-Los Angeles Counties Water Reuse Study, specifically on the completion of the Health Effects Task. Groundwater management at Whittier Narrows is under detailed study as a part of the Task.

In California, the consideration of water quality standards for well injection into undergound water-supply aquifers is on a case-by-case basis. However, it appears that approval might be granted for the following pretreatment, under certain conditions:

- source control of toxic industrial chemical compounds
- adequate disinfection
- oxidation
- coagulation
- clarification
- filtration
- GAC adsorption
- reverse osmosis (R.O.)
- decarbonator type stripping for volatile low molecular weight organics

At the Orange County (Calif.) Water District, Water Factory 21 has been operating this treatment train. It also operates a similar one which omits filtration and GAC adsorption, without loss of quality in the reclaimed water being injected.

Presently, the process differences in pretreatment requirements between water for surface spreading and well injection is the elimination, in the case of surface spreading, of the requirements for disinfection, chemical treatment, filtration, reverse osmosis, and stripping. However, if the current study at Whittier Narrows is favorable, the pretreatment standards for surface spreading may be liberalized.

Nitrogen--

Under certain conditions of surface spreading the fate of nitrogen can be a problem. Under optimum conditions crops will take up the nitrogen which will then be removed when the crops are harvested. However, if excess water is spread, ammonia may enter the aquifer, and, in the event that no crops are grown, ammonia may be converted to nitrate in the soil which may eventually enter the aquifer. Depending upon the dilution afforded by natural recharge, ammonia or nitrate can become a problem.

In the case of well injection, if nitrate concentrations are a problem, there may be relief by the use of polyamide membranes rather than cellulose-acetate membranes in the R.O. process. The polyamide membranes are not pH sensitive and remove up to 99 percent of applied nitrates.

Trace Organics--

The trihalomethanes problem may be less in reclaimed wastewater than it is in natural water supply sources. As shown by Table 2, data from operating water reclamation projects indicate that chlorinated organic problems are less than for public water supplies. This is due to the presence of ammonia in the wastewater that, in combination with applied chlorine, forms chloramines which act as the disinfectant. Trihalomethane production by chloramine disinfection is extremely low. Even though there probably are other organics of concern, indications are that resolution of the trace organics problem in reclaimed water will be simultaneous with resolution of the same problem in existing drinking water supplies.

Virus--

In well injection for direct recharge of groundwater, the most positive solution to potential virus problems is disinfection prior to injection. There are several rather well known means for accomplishing this. Some engineers may question the need for complete inactivation of virus prior to injection. However, it is the safest course to follow in view of the observed tendency of virus previously removed by adsorption in coarse granular beds to desorb and move short horizontal distances in slugs when flow through the aquifer is suddenly increased.

In the case of indirect recharge by surface spreading where there is a soil layer at the surface, virus removal is excellent by natural processes, and it is doubtful that disinfection is necessary prior to spreading. This is recognized in the current California guidelines. Pretreatment to insure complete virus inactivation is rather costly and may not properly credit the ability of the soil column to remove virus by filtration, adsorption, and other natural means. The desorption and travel of previously adsorbed virus is not the problem in vertical

TABLE 2. ORGANIC CHEMICALS IN PUBLIC WATER SUPPLIES AND IN RECLAIMED WASTEWATER
(Concentrations in milligrams per liter)

Organic Substance	1976 U.S. EPA National Organics Monitoring Survey of 113 Public Drinking Water Supplies				Organics in Reclaimed Wastewater		
	Phase I	Phase II	Phase III		So. Tahoe P.U.D. Feb. 1980	Orange County Water Dist.	
	Terminal	Terminal	Dechlorinated	Terminal		Oct. 1976 to March 1978*	March 1978 to Jan. 1979
Chloroform:							
Median	0.027	0.059	0.022	0.044			
Mean	0.043	0.083	0.035	0.069	0.010	0.007	0.009
Range	NF-0.271	NF-0.47	NF-0.20	NF-0.540			
Bromoform:							
Median	LD	LD	LD	LD			
Mean	0.003	0.004	0.002	0.004	Less than 0.001	Less than 0.001	Less than 0.001
Range	NF-0.039	NF-0.280	NF-0.137	NF-0.190			
Dibromochloromethane:							
Median	LD	0.004	0.002	0.003			
Mean	0.008	0.012	0.006	0.011	Less than 0.001	Less than 0.001	0.001
Range	NF-0.190	NF-0.290	NF-0.114	NF-0.250			
Bromodichloromethane:							
Median	0.010	0.014	0.006	0.011			
Mean	0.018	0.018	0.009	0.017	0.001	0.002	0.003
Range	NF-0.183	NF-0.180	NF-0.072	NF-0.125			

NF = not found LD = less than detection limit
*Breakpoint chlorination

travel of water in fine soil that it may be in horizontal travel through coarse aquifers.

Treatment Requirements for Surface Water Recycle

The subject of this Symposium is to develop the protocol or procedures which may lead to establishment of criteria and standards for potable reuse systems. One approach to stimulating a discussion of this subject is to propose a system of treatment and the water quality that such treatment might be expected to produce, and then to analyze it for possible deficiencies, shortcomings, or objections.

There is, of course, a whole universe of engineering options for converting wastewater to potable water. In any system, the control at the source over possible discharges of toxic substances into the wastewater collection system is an absolute necessity. Spill prevention and mitigation are important factors in wastewater reuse, as they are in all public water supply sources.

The water reclamation process selected for presentation and critical analysis here is one which might serve for a program of successive reuse. It also could serve for a once through system, either as is, or with deletion of R.O., or with the addition of ground or surface storage. This may be considered by some engineers to be a rather conservative system, but it should serve to illustrate most of the processes and conditions which might be involved in almost any project.

This system includes:

1. Source control of toxic industrial chemical compounds
2. Preliminary treatment
3. Primary treatment
4. Aeration by activated sludge
5. Secondary sedimentation
6. Lime addition to pH = 11
7. Flocculation
8. Chemical clarification
9. pH adjustment by recarbonation
10. Flow equalization (or prolonged storage)
11. Mixed media filtration
12. Selective (ammonia) ion exchange
13. Breakpoint chlorination
14. Granular activated carbon (GAC) adsorption
15. Reverse osmosis
16. Ozonation
17. Chlorination
18. Regeneration of ion exchange media
19. Reaction of GAC
20. Sludge processing

This system is quite similar to the treatment system proposed for the Denver successive reuse program. At Denver this train of unit processes will be subjected to intensive and extensive testing and analysis at a pilot plant scale of 1 mgd (million gallons per day).

This system is also quite similar to that now utilized at full plant scale (15 mgd) by the Orange County (California) Water District to prepare water for well injection to underground aquifers to control sea water intrusion.

Process Train Performance

The performance of the treatment train described immediately above is presented in Table 3. The information on which Table 3 is based was collected and subjected to statistical analysis under a recent study performed for the Office of Water Research and Technology of the U.S. Dept. of Interior[1]. It shows not only the average removals in percent, but also provides a measure of the reliability of the process train by giving the performance obtained (in the group of treatment plants studied) 10, 50, and 90 percent of the time. In addition, Table 3 lists the average effluent concentrations from the plants studied. The contaminant removal capabilities and the reliability data were developed from information obtained from a large number of operating full scale plants and from pilot test facilities across the country.

Costs of Pretreatment, Groundwater Recharge, and Surface Water Recycling

Because pretreatment requirements for recharge vary considerably from state to state, and since they are in transition in California, a range of pretreatment processes will be covered by estimates, so that rough preliminary costs will be available for most situations likely to be encountered.

Table 4 summarizes pretreatment and recharge costs for five sets of conditions. In addition to liquid processing costs, sludge processing costs are included. Four degrees of pretreatment are shown for surface spreading, and one for well injection. The lowest cost system is for secondary treatment in aerated lagoons followed by surface spreading. The next set of conditions is secondary treatment by the activated sludge process followed by surface spreading. The third example is one which probably corresponds to current California guidelines for surface spreading. It includes activated sludge, filtration, and GAC adsorption. The fourth exceeds California requirements but may be useful in some situations. It includes activated sludge, high-lime clarification, recarbonation, filtration, GAC adsorption, and chlorination. The fifth and last basis for cost estimates is that which might be suitable for well injection into an aquifer which is used as a potable water source: it includes activated sludge, high-lime treatment, recarbonation, flow equalization, filtration, ammonia removal by ion exchange, breakpoint chlorination, GAC adsorption, reverse osmosis, ozonation, and chlorination. To demonstrate economies of scale, estimates are given 1, 10, and 50 mgd systems. The last estimate of costs also applies to surface water recycling for the combination of unit processes shown.

It is hazardous to generalize on the costs of reclaimed water obtained from recharged groundwater supplies or recycled surface water sources versus the costs of developing new fresh water supplies for potable purposes because local

TABLE 3[1]. PROCESS TRAIN PERFORMANCE

(Act. sludge, hi-lime, recarb., flow equal., ion exch., bk.-pt. Cl_2, GAC adsorption, R.O., ozonation, and chlorination)

Constituent	Average Removal, %	Average reliability 10%	50%+ (% Removals)	90%	Average effluent concentration, mg/l
BOD	100	100	100	89	0
COD	100	100	100	97	<1
TSS	100	100	99	87	0
NH_3-N	100	100	91	68	0
Phosphorus	100	100	100	99	0
Oil & grease	100	100	100	90	0
Arsenic	61	93	63	0	.003
Barium	79	95	79	52	.092
Cadmium	98	100	98	87	.0002
Chromium	100	100	98	84	0
Copper	98	100	99	98	.002
Iron	99	100	100	94	.023
Lead	99	100	98	78	.001
Manganese	98	100	98	86	.002
Mercury	23	31	18	0	.028
Selenium	7	26	12	0	.006
Silver	82	100	99	80	.004
Zinc	98	100	95	58	.008
TOC	100	100	98	83	<1
Turbidity	100	100	100	95	<0.1*
Color	93	100	94	56	5**
Foaming agents	92	-	84	-	.17
TDS	95	-	-	-	129

*TU

**P-C Units

+Median removal

Symbols: x - data inconclusive

- - insufficient data

TABLE 4. SUMMARY OF COSTS* FOR PRETREATMENT, GROUNDWATER RECHARGE, AND SURFACE WATER RECYCLING (Including sludge processing costs)

Method	Treatment system	Unit cost ¢/1000 gal 1 mgd	 10 mgd	 50 mgd
Surface spreading	Secondary treatment in aerated lagoons (minimum pretreatment)	38.1	19.7	15.8
Surface spreading	Secondary treatment by activated sludge (Whittier Narrows type proj.)	127.3	59.6	52.8
Surface spreading	Activated sludge, filtration, GAC adsorption	200.2	84.6	64.6
Surface spreading	Activated sludge, high-lime, recarb., filtration, GAC adsorption, chlorination	238.7	100.6	75.5
Well injection or surface water recycling	Activated sludge, high-lime, recarb., flow equalization, filtration, ammonia removal by ion exchange, breakpoint chlorination, GAC adsorption, reverse osmosis, ozonation, and chlorination	481.3	214.6	171.8

*Sept. 1977 costs

conditions vary so greatly from place to place and play such a major role in determining the costs involved. However, it may be helpful to make a few very general cost conclusions, despite the obvious limitations.

1. At the present time for municipal purposes, reclaimed wastewater is not cost competitive with new fresh water sources except in a limited number of locations and special circumstances.

2. For municipal purposes at capacities above 10 mgd, the costs for developing and treating fresh water from new sources are in the same general range as water produced by groundwater recharge using the lowest cost system.

3. For municipal purposes at capacities above 100 mgd, water from even the most sophisticated groundwater recharge system or surface water recycling system may be competitive in cost with development of new fresh water supplies in certain locations, such as Denver and Southern California where the costs for new supplies are high.

In Table 4 cost data are given for only the reuse systems which appear at the moment to be of the most interest. There are, of course, numerous other systems which may be used for the same purposes and others, at higher or lower total costs. To aid in modifying the costs of the systems given in Table 4, and to assist in estimating the costs of alternative reuse systems, unit costs of wastewater treatment are given in Table 5. Table 5 is also taken from the 1979 OWR, Dept. of Interior report[1].

MONITORING AND PROCESS CONTROL*

General

There is now available a wide variety of on-line monitoring equipment, automatic testing equipment, laboratory apparatus, and computerized control equipment which is used in water and wastewater plants and laboratories. Both for existing water and wastewater plants and for future potable reuse systems, it would be valuable if the presently available monitoring and process control systems could be supplemented by one or more of the following:

1. Rapid identification of bacteria
2. Rapid detection of virus
3. Simple field tests for overall evaluation of toxicity
4. A satisfactory measure of total organics in water

TABLE 5[1]. UNIT COSTS** OF WASTEWATER TREATMENT

	Unit cost, ¢/1000 gal		
Treatment system	1 mgd	10 mgd	50 mgd
Activated sludge	100.0	47.4	36.3
Trickling filter	104.7	52.6	39.5
Rotating biological contactors	107.2	65.1	55.8
2-Stage nitrification	130.7	58.8	44.7
Rotating biological contactors, nitrification	142.3	98.2	85.0
Extended aeration	43.2	28.4	-
Nitrification-denitrification	150.2	73.2	56.0
Selective ion exchange	189.3	89.9	65.5
Filtration of secondary effluent	132.8	55.1	42.7
Alum added to aeration basin	172.8	70.3	57.4
Ferric chloride added to primary	156.4	77.5	57.8
Tertiary lime treatment (Incl. Act. Sludge)	196.1	81.7	59.3
Tertiary lime, nitrified effluent	217.0	83.0	60.6
Tertiary lime plus ion exchange	224.4	108.9	77.2
Carbon adsorption, filtered secondary effluent	176.5	72.7	57.2
Carbon, tertiary lime effluent	238.7	99.4	74.2
Carbon, tertiary lime, nitrified effluent	263.8	100.6	75.5
Carbon, tertiary lime, ion exchange	288.0	126.5	91.9
Reverse osmosis of AWT effluent	481.3	214.6	171.8
Physical-chemical system, lime	250.4	103.3	81.2
Physical-chemical system, ferric chloride	255.6	115.0	86.4
Irrigation	79.5	61.5	53.5
Infiltration-percolation	38.1	19.7	15.8
Overland flow	52.4	35.4	30.1

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*Much of the data in this section is taken from Reference (6)

**September 1977 costs

These development tasks present a difficult challenge, and it may be that none of them will be met. However, existing water and wastewater treatment plants will continue to operate, and to operate with a high degree of safety without these new aides. There appears to be no reason why potable reuse systems could not do likewise. However, to do this, consideration must be given to presently accepted practices and procedures in the water works field which may be applicable to wastewater renovation.

Bacteria

For example, the results of bacteriological tests of potable water samples are not known until after the water has been distributed to customers and consumed. In other words, the bacteriological quality of the water is not definitely confirmed by actual test at the time of processing or use, but only some time after it has been consumed. The principal assurance of bacteriological quality in drinking water is the fact that the water treatment process used, especially the disinfection procedure, is known to produce a certain result when it is operating normally. If operations deviate from normal or give early indications that they are about to do so, then the operator makes the necessary corrections to restore operations to normal. This occurs daily in water treatment plants across the Country. In virtually all instances there is no breakdown or loss in the bacteriological quality of the water. Several days later this fact, which is already evident to the operator, is confirmed by laboratory test results. Thus, bacteriological tests of drinking water are still, as they always have been, for purposes of confirmation that there have been no failures in treatment and have limited value for control of plant operations. Some sources of public water supply namely properly located and protected wells, may be bacteriologically safe at the source prior to disinfection, which adds to safety of supply, but virtually all surface water sources require disinfection to assure safety.

Bacteriological tests, if negative, provide a record of the good quality, but, if positive, are rather a late warning. Loss of chlorine residual or a rise in turbidity, if observed, may give an earlier warning of potential bacteriological trouble. All of this has been accepted as good water works practice for the past 50 years, and no serious health consequences have resulted. If an instantaneous means were developed for detection of coliform organisms, it would be quite comforting to academicians, but might not produce any great practical improvement in the actual bacteriological quality of public drinking water supplies.

Producing bacteriologically safe drinking water from wastewater may differ slightly from that just described for conventional water supply sources. Depending upon the degree of wastewater pretreatment provided, wastewater sources may contain higher concentrations of bacteria and have greater chlorine demand due to the presence of ammonia or other substances. However, by providing proper initial mixing of the chlorine, by proper pretreatment, and by any necessary increase in chlorine dosage or contact time, a coliform-free water can be produced from wastewater even in the presence of ammonia. This has been well demonstrated at several operating AWT plants.

The question of chlorine demand and reduce germicidal effectiveness in the presence of ammonia always arises in connection with wastewater renovation. It appears from recent good experience with chlorination in the presence of ammonia, that there is still much to be learned about chlorine-ammonia treatment. It also may be that the importance of pH as it affects the speed of chloramine formation and the importance of initial mixing may not have been given sufficient weight in early studies of chlorine-ammonia treatment. Additional research in this area may be warranted.

The 1977 NAS (National Academy of Sciences) report on Drinking Water and Health states: "Current coliform standards are not satisfactory for water reclaimed directly from wastewater. Meeting current coliform standards for water reclaimed directly from wastewater, or from water containing several percent of fresh sewage effluent is insufficient to protect public health. For such raw water suplies, new microbiological standards should be developed and applied as supplementary to colifom standards."

To meet this concern, attention must be given to supplemental standards, which might include fecal coliform standards, or total plate count requirements, or other additional safeguards. This probably can be done using existing methods and without the necessity of developing new laboratory procedures.

An example, which might be followed, is given by W.H.S. Hattingh in the South African "Manual For Renovation and Reclamation"[8]. In regard to operation of the Stander wastewater reclamation plant which supplies drinking water to the public, he states:

"The microbiological studies indicated that a standard of 0 coliforms per 100 cm^3, a total plate count of <100 per cm^3 and no detectable enteric viruses per 10 dm^3 is an adequate and practical criterion for routine testing of reclaimed water and that a water which conforms to these standards should have no adverse effects on the health of the consumer."

Virus

The situation with respect to virus in water purification and in wastewater renovation is a close parallel to that regarding bacteria. However, in virus inactivation, final dependence rests entirely upon disinfection under proper conditions for production of virus-free water from any source. Virus recovery procedures are constantly and rapidly improving, but there are some virus for which there is no method of recovery. Except for a few water works in the largest cities, virus tests are not run routinely on public water supplies; reliance is placed upon proper operation of disinfection facilities to assure safety from virus. There is not a great deal of information available on virus in public water supplies.

In the October, 1969 Journal AWWA a Virus Committee report by Clarke, Berg, Liu, Metcalf, Sullivan, and Vlassoff summarizes very well and completely the status of viruses in water at that time. Excerpts from this report follow:

"There is no doubt that water can be treated so that it is always free from infectious microorganisms-it will be biologically safe. Adequate treatment means clarification (coagulation, sedimentation, and filtration), followed by effective disinfection. Effective disinfection can be carried out only on water free from suspended material." The Commmittee concluded that for most effective disinfection they felt it would be best to keep the turbidity as low as 0.1 T.U., as recommended by AWWA water quality goals. With turbidities as low as 0.1 to 1 T.U., they concluded that a pre-plant chlorine feed need be only enough to have a 1 mg/L free chlorine residual after 30 minutes contact time. Postchlorination practice would then depend upon the ability to maintain such residuals throughout the distribution system. Thus, the disinfection of water is dependent upon optimizing the unit processes of chemical coagulation, sedimentation, and filtration (which in themselves provide substantial reductions in bacteria and viruses) to produce minimum water turbidities to assure the maximum contact between any remaining pathogens and the disinfectant added.

The experience with virus removal in AWT has been good, even with chlorination in the presence of ammonia. However, viruses have been isolated on a few occasions at Water Factory 21 and in pilot plant research at Pomona, California.

As with bacteria, it appears that water works practice in virus inactivation can be safely transferred with few modifications to wastewater renovation. There is a known set of treatment conditions that historically has provided drinking water with acceptable virus quality. However, there probably is more question about chlorine-ammonia treatment in the case of virus than with bacteria.

Chlorine-ammonia disinfection has an advantage over free chlorination which is similar to that provided by ozone and chlorine dioxide in the use of ammonia with chlorine limits or stops trihalomethane production. The free chlorine reacts first with the ammonia to produce chloramines. The chloramines do not react with organics, thus limiting trihalomethanes production. It may be worthwhile to conduct new studies of virus inactivation by chlorine-ammonia treatment for several reasons. One would be to compare its trihalomethane production with that of other disinfectants. A second reason would be to determine over a range of pH values and under different conditions of initial mixing the rates at which three different chlorine reactions are completed during (1) virus inactivation, (2) chloramine formation (complete loss of free chlorine), and (3) trihalomethane formation.

Because the efficiency of virus inactiviation by chlorine in the presence of ammonia and organics will undoubtedly be questioned, it would appear that literature review and research in this area should have high priority. The information developed will also be valuable in water purification practice.

Demonstrated accepted virus inactivation by free chlorine in chlorine-ammonia treatment rather than by free residual chlorination could greatly reduce the costs of wastewater renovation.

Research should be continued with various active ozone species for virus inactivation. Better definition of the mechanics and kinetics of ozone in water and wastewater are needed to establish time-concentration relationships which will assure the desired results in the field. Ideally, an ozone disinfection process can be developed which will give results so uniform that use of a specified ozone treatment technique will be accepted as evidence of good biological quality. Some further confirmation for record purposes could be afforded by use of the latest concentration-isolation procedures for virus recovery and identification. This treatment technique with test follow-up would correspond to presently accepted practices with regard to bacteriological quality in the water works industry. Also, research should be done on possible formation of harmful organic by-products in ozonation.

Toxic Substances

The NIPDWR specify MCL's for ten inorganic chemicals and six organic chemicals. Monitoring and analytical requirements for public surface water supplies consist of annual sampling and analysis for the inorganic chemicals and sampling and analysis at three-year intervals for the organic chemicals. The requirement for tests at such infrequent intervals indicates that once the safety of supply with regard to these elements is established that major variations in content are not expected. It would appear that similar test procedures could be applied to wastewater renovation. As in the case for fresh water sources, if there is reason to suspect that spills or other changes have occurred, more frequent sampling could be demanded.

For most of the toxic substances (not including nitrate) for which MCL's are set in the NIPDWR, the limits are based on no ill effect for lifetime exposure to water not exceeding the limit set.

The report of the EPA Advisory Committee on the Revision and Application of the Drinking Water Standards says:

"Waters reclaimed from treated community wastewater as a source received considerable discussion. Treated domestic, industrial, and other wastewaters may contain many substances not significantly present in natural waters and are not included in these Standards. Such substances in sufficient concentrations could be hazardous to health or otherwise objectionable. It is not possible, at this time, to identify the constituents of potential concern, much less set limits therefor. Moreover, limits for innumerable substances would require an impossible burden of analytical examination."

The Committee is correct in its assessment that standards and tests for all constituents of potential concern present an impossible condition to satisfy. If it is also correct in its contention that the toxicity standards do protect conventional water supply sources, including badly polluted ones, but do not adequately protect water produced by wastewater renovation, then a difficult problem is presented.

On-Line Monitoring of Toxicity

Cytological assay has shown some promise. Difficulties with this approach include: the time required to obtain results; the possible lack of sensitivity to unconcentrated renovated wastewater; and adaptation to field handling.

Even if the outcome of additional research to develop an on-line monitor for toxicity is completely successful from a technical standpoint, some time will be required for the procedure to be accepted by the scientific community, and a longer time for political and public acceptance. If an on-line toxicity monitor is not developed, then questions can be raised about each of the hundreds of organic compounds which may be present in wastewater. Conceivably this could indefinitely delay acceptance of wastewater reuse by regulatory agencies.

Trace Organics

The toxic substances which are most likely to be troublesome in renovated wastewaters are not the metals for which the NIPDWR specifies MCL's, but, rather, any organic compounds that are not removed by biological, physical, and chemical treatment processes.

Research has determined the total TOC and the fraction of volatile organic solutes in wastewaters treated by screening, ultrafiltration, micro filtration, reverse osmosis, UV-catalyzed ozonation, and hypochlorination. These studies showed that volatile organics accounted for 13-73 percent of total TOC remaining after R.O., and 30-73 percent after ozonation. Five volatiles quantitated by the technique used were methanol, acetone, 2-propanol, diethyl ether, and methyl ethyl ketone. The fact that volatile organics make up a sizeable portion of the TOC in R.O. permeates, suggests that air stripping might be a candidate process to add to the treatment train. This suggestion is based on preliminary data which has been obtained at the Orange County Water District Water Factory 21 (WF 21). At WF 21, full-scale (15 mgd) plant tests were run using air stripping. The removals of certain selected organics and of chloroform and other trihalomethanes were measured. Some of the results are shown in Table 6.

Perhaps the most difficult area or research regarding potential health effects of renovated wastewater is the possible carcinogenicity of trace organics. As has been mentioned previously, this is a problem which is shared with all existing public water supplies.

TABLE 6. ORGANIC REMOVAL BY AIR STRIPPING, WATER FACTORY 21

Organic	Mean percent removal
Ethylbenzene	80
Chlorobenzene/o-xylene	60
1,3 Dichlorobenzene	80
1,4 Dichlorobenzene	90
1,2 Dichlorobenzene	70
1,2,4 Trichlorobenzene	50
Napthalene	40
Carbon Tetrachloride	95
PCB's	97
Trichloroethylene	98
Methylene Chloride	92
Chloroform	80

In considering the question of trace organics and potential long-term health effects there are at least three possible approaches:

1. Attempt to select or develop a satisfactory measure of total organics in water, and to establish a MCL based on this overall parameter.

2. Try to select specified treatment techniques which would satisfy health concerns with regard to trace organics.

3. Supplement research already underway in the identification of the whole host of organics in water and find a MCL for each new potentially harmful organic identified.

All public water supplies from both well and surface sources contain organic matter. Many of the organic compounds have been identified, but the total number of trace organics numbers in the hundreds, and it will be many years, if ever, before all are identified.

Enough presumptive evidence has been gathered to arouse serious concern in public health circles. EPA officials have weighed the facts at hand and proposed a MCL for trihalomethanes and a granular activated carbon treatment technique for supplies containing synthetic organics.

Renovated wastewaters could meet the MCL for trihalomethanes quite easily. Experience at the Orange County Water District's Water Factory 21 has already demonstrated that their reclaimed wastewater is superior to many existing public water supplies with respect to trihalomethane content (see Table 2). The total trihalomethane concentration for WF 21 reclaimed water averaged 18 g/l, compared to the average of 95 g/l terminal concentration found by the EPA in their national organic monitoring survey of drinking water supplies in 113 cities. Also, 18 g/l is well below the limit of 100 g/l established for total trihalomethanes.

Further, most treatment processes proposed for wastewater renovation already include a higher degree of granular activated carbon treatment than that which EPA has prescribed to be added to existing water supplies which are polluted by synthetic organics.

These two proposed regulations are being vigorously opposed by operators of public water supplies which have polluted sources of supply on the basis that such regulations are unnecessary for health protection. The CSSE (Conference of State Sanitary Engineers) has also questioned the need for the proposed organics regulations. On the other hand, potential purveyors of reclaimed water would agree, in all likelihood, to meet the trihalomethane standard and, further, would provide the carbon treatment.

Regardless of the outcome of the controversy with respect to organics in water supplies, further resolution may be required with regard to renovation of wastewaters. The rationale behind the EPA proposal of a treatment technique as a remedy for the synthetic organics problem in water supplies strongly suggests that this may also be the best approach for wastewaters. The EPA originally set out to establish safe levels for each of the organics of concern. However, when it became evident that the number of these organics extended to many hundreds, the only practical solution which could be reached in any reasonable length of time was to use a specified treatment technique rather than to attempt to establish MCL's for each organic compound. This reasoning suggests that whatever effort is to be expended toward development of quality criteria for organics in renovated wastewater should be directed at a treatment technique rather than a standard for some measure or organics.

Reliability of Water Reclamation Processes

The reliability of a process train commonly considered for wastewater reclamation in removing contaminants of concern is given in Table 3.

The subject of treatment reliability could well be the subject of a separate, extensive report.

Reliability of wastewater treatment can be defined or measured using one of several systems, but it is generally considered as being the chance of meeting, or not meeting, a preset limitation. This definition introduces the idea of probabilities which describe the variability in plant performance. In general, treatment plant data can be described by an arithmetic or log probability distribution function, which, more often than not, is skewed towards the higher values.

Determination of the degree of reliability for a particular reuse system can be accomplished by many methods, but they all require some degree of subjective interpretation of the results of an analysis. Frequently, the degree of reliability and the setting of effluent quality standards become an emotional issue in which the finally adopted values cannot be defended on a statistical basis. The most logical method of setting reliability requirements might be a detailed cost/benefit analysis, but the cost/benefit method is seldom if ever used to establish treatment reliability. In many instances, the average and maximum values to be obtained by a treatment plant are set using judgement and the values typically obtainable by a well-maintained and operating plant. Another way of setting the degree of treatment reliability is to set the maximum value at a point just below the level causing toxicity or some other problem; and to set the average using typical values obtained in operating plants.

Once the reliability for either a treatment system or the individual contaminants has been established, the design engineer can design a treatment system that will meet the standards. There are two basic methods that can be used for design: (1) designing the plant based on influent data, and (2) designing the plant to achieve an effluent quality which is based on probablistic functions.

The first method requires the construction of cumulative probability distributions of the influent mass flux for the contaminants of interest.

The second method is dependent upon having available effluent probability curves which are related to a parameter such as BOD, suspended solids (SS), or others.

The data presented in Table 4 were developed to provide the necessary information to estimate the reliability of various treatment processes. Knowing the influent wastewater characteristics, an effluent quality can be computed with a predetermined degree of reliability. This approach permits the selection of different reliabilities for the contaminants of concern; therefore, unit processes can be selected on the basis of the highest reliability and then checked to ensure that the required removal reliability of the contaminants of less concern is achieved.

In addition, all treatment processes should be provided with the necessary redundancies to ensure that the treatment plant can operate adequately with certain facilities out of service.

Equipment and Process Redundancy

As an example the California Administrative Code (Title 22, Division 4) establishes regulations for treatment plant reliability. The intent of the regulations are described in the following excerpt from the code:

"The intent of these regulations is to establish acceptable levels of constituents of reclaimed water and to prescribe means for assurance of reliability in the production of reclaimed water in order to ensure that the use of reclaimed water for the specified purposes does not impose undue risks to health. The levels of constituents in combination with the means for asurance of reliability constitute reclamation criteria as defined in Section 13520 of the California Water Code."

The Code provides for the reliability of effluent quality by requiring either storage or process and equipment redundance.

Another example of equipment and process redundancy requirements are those set for the Upper Occoquan Sewage Authority by the Virginia State Water Control Board. These are summarized because they represent what is probably as strict and comprehensive a set of redundancy requirements as have been imposed to date on water reclamation. The essence of the policy for the Occoquan Watershed is contained in the following excerpts:

"The initial backup capacity within the plant shall be 100% for the initial increments of the plant. If after the initial few years of operation the plants reliability has been satisfactorily demonstrated, additional treatment trains can be added up to a ratio of four treatment units to one stand-by train."

"The design shall be such that expansions and maintenance of any unit can be accomplished without by-passing wastes or degrading treatment."

"The mechanical and fluid system design shall be such that a single failure of a component or unit shall not interrupt plant operations which are required to meet the final effluent requirements---."

"There shall be two independent sources of outside power and one on-site power supply. Both off-site and on-site electrical distribution shall be such that the failure of any one given component (mechanical or electrical) in the distribution system shall not cause an interruption of electrical service to parts of the plant which are essential to meet the effluent requirements---."

The Occoquan AWT plant built under these requirements has been constructed and is now in operation.

RESEARCH & DEVELOPMENT NEEDS

General

It may be entirely possible to develop potable reuse criteria and standards on the basis of present knowledge, and without waiting for the results of ongoing or proposed future research. Undoubtedly, research will produce refinement in the standards, which regardless of when promulgated, should always be updated and improved in the light of new knowledge. Even if the economics of meeting standards produced at the present time makes projects infeasible, or if the first set of standards is imperfect, a serious attempt to develop such criteria and standards may be worthwhile at this time. A starting point is needed.

W.H.O. Recommendations[9]

In 1973 WHO experts summarized (1973) research needs for water reuse as follows:

> "Further research is required in the following areas, in which the present state of knowledge is known to be insufficient:
>
> "1. The potential long-term health effects of trace materials and residues remaining after conventional water treatment. Research on this topic should include both physiological investigations on individuals known to have been using drinking-water derived from polluted sources and toxicological studies on the waters themselves under laboratory conditions."
>
> "2. The improvement of methods of identifying, measuring, and monitoring chemical and microbial pollutants. Rapid identification of bacteria and viruses is required, and there is a need for a means of monitoring chemical pollutants by simple field tests, without the use of expensive equipment and highly qualified analytical staff."
>
> "3. The development and improvement of treatment and separation processes suitable for use in many parts of the world. The reliability of treatment processes should be increased, and a more accurate determination should be made of their capabilities, separately and in combination, to remove different types of contaminant in varying concentrations."

Boulder Workshop Recommendations

In 1975, in an effort to identify research priorities and to provide EPA with direction for conducting its municipal wastewater potable reuse research program, EPA, AWWA, and WPCF (Water Pollution Control Federation) conducted a workshop at Boulder, Colorado.

The workshop was three days in length and was designed for persons involved in the use, conduct, direction, or specification of research in the wastewater renovation and reuse field. WPCF and AWWA, and selected representatives of federal, state, municipal, industrial, academic, and consulting organizations participated. In addition to presentations on specific reuse situations that included both native and foreign experience, papers were presented on (1) potential health hazards of using wastewater for domestic purposes, (2) the status of existing technology that can be used to properly treat wastewater for reuse, and (3) the socio-economic aspects of reuse. The presentations established the state-of-the-art, or "where we are now."

The findings of this workshop were summarized in a paper[7] entitled, "Research Required to Establish Confidence in the Potable Reuse of Wastewater", by John N. English (EPA), K.D. Lindstedt, and Edwin R. Bennett at the 1975 WPCF meeting in Miami, Florida.

The research needs associated with the potable reuse of municipal wastewater was identified under six categories: (1) Treatment, (2) Treatment Reliability and Quality Control, (3) Health Effects - Inorganics, (4) Health Effects, Organics, (5) Health Effects - Biological, and (6) Socio-Economics Aspects.

The conclusions of the workshop were summarized by English, et al, as follows:

"It is anticipated that a program undertaking the research previously described will require a minimum of 10 to 15 years of intensive work to develop sufficient information to clearly define meaningful standards that can be applied with confidence to potable waters derived from a polluted source. These standards will have to be based on realistic public health considerations and have the support of public health officials at all government levels."

"The goals of a direct or overt potable reuse program are similar to those of the present EPA Health Effects and Water Supply programs which have recently identified organic materials having potential health hazards in many of our nation's drinking waters. Some of these supplies contain appreciable quantities of wastewaters, and their use for domestic purposes can be classified as an indirect or covert form of potable reuse."

"There was a general consensus of the workshop attendees that the research identified must be addressed by both water supply and wastewater organizations. Even if direct reuse is not implemented, all same questions which have been raised must be answered, and the technology must be developed to remove potential health hazard constituents present in our water supplies."

"Any program of the magnitude required to alleviate the health concerns of both overt and covert potable reuse is not a local or even a national undertaking. International coordination is necessary since other nations such as South Africa, Israel, and some in the European community are facing deteriorating and unreliable water supplies, and are actively researching the problems involved with covert and overt potable reuse."

"The research identified at the workshop will be used to lay out a long range approach which will utilize the results from the ongoing EPA Wastewater, Health Effects, and Water Supply Programs. By clearly defining a strategy for potable reuse the results from these programs can be used as 'stepping stones' for a future potable reuse research program."

These two views of research needs are typical of the time (1973-1975) with regard to municipal reuse. Current views probably do not differ greatly from these, although the organics problem is now recognized as being a potential problem for all public water supplies regardless of source of supply, and the problems of trace organics in existing polluted sources of supply is considered by many health authorities as being a greater problem than it was thought to be four or five years ago.

Research Priorities

There are several lines of research which should be persued either to develop or improve standards and criteria for water reuse. In the order of priority they are:

1. Specify or develop treatment techniques or monitoring procedures which will satisfy health concerns with regard to trace organics.
2. Specify or develop treatment techniques or test procedures which will assure water safe from virus hazards.
3. Develop rapid test for presence of pathogenic bacteria.

It is very difficult to assess precisely the value of the successful completion of any one or all of these research projects toward development or acceptance of quality criteria for renovated wastewater. Certainly, if all were fully successful, the task should be much easier, but a positive result would not be assured, because opposition to potable reuse is based not only on technical considerations but upon emotional and political motivations as well.

SUMMARIZATION OF ISSUES

The Key

The key to acceptance of wastewater reuse for potable purposes is the declaration by a recognized and respected scientific authority (such as the National Academy of Sciences) that reuse is safe from a health standpoint.

Possible Procedural Approach

In reference (6), a plan is outlined for development of water quality criteria for specific military wastewater reuse applications. A similar approach might be suitable for municipal reuse applications. Basically, this approach involves an organized effort by some interested group (say the EPA, Department of Interior, AWWA, or other agency) to develop water quality criteria for potable water derived form renovated wastewaters and submit criteria to interested local, state and Federal health agencies for comment and finally to the NAS for approval.

An agency undertaking the task of Potable Water Quality Criteria Development might elect either to do the job internally with its own forces, or to contract with an outside organization. If it is to be done internally, an advisory panel might be utilized. If it is to be done externally, a contract arrangement might be considered with a consulting firm or directly with NAS. At best, criteria development may take a period of 2 to 4 years. At the outset, if there are obvious health effects research projects needed, they should be identified and pursued simultaneously with criteria development. Consideration should be given to health effects research projects in the areas of: (1) bacteria and virus, (2) trace organics, and (3) toxicity.

The Criteria Development Agency or Contractor should perform the tasks shown in Table 7.

TABLE 7. PLAN OR DEVELOPMENT OF WATER QUALITY CRITERIA FOR WATER DERIVED FROM RENOVATED WASTEWATERS[6]

A. Review literature
    1. of existing standards for drinking water derived from conventional sources and related background studies
    2. reports of health effects research
    3. design and operating reports of wastewater reuse projects especially those in;
        a. Denver
        b. South Africa
        c. Israel
        d. Orange County Water District
        e. Upper Occoquan Sewage Authority
    4. water and wastewater treatment methods
    5. analytical and monitoring methods

B. Review ongoing health effects research in areas of:
    1. bacteria and virus,
    2. trace organics removal, and
    3. toxicity evaluation

C. Prepare report for presentation to health officials for comment and NAS for approval. This report would, or course, contain the proposed criteria

The potential effect of new related health effects research on the acceptance and approval of the quality criteria is difficult to evaluate. It may be possible to gain scientific and health approval on the basis of complete assembly and good presentation of existing information. It is also possible that research completed in the next few years could be a decisive factor. Or, it may be that potable reuse of renovated wastewater will not ever be approved regardless of favorable scientific, health, and engineering facts. It may fail on the basis of aesthetics, lack of public or political acceptance, or for other reasons outside the influence of research results.

At this time, it appears that criteria for potable reuse are not going to receive much consideration unless an organized effort is made by some agency to develop a set of criteria and the supporting data for presentation to scientific and health authorities. Without such an concerted organized effort, it is unlikely that recognized scientific authorities will accept wastewater reuse for potable purpose or declare reuse safe from a health standpoint. The need for reuse must also be demonstrated.

Presently, water supply people in the U.S. are not motivated to initiate water reuse projects, even though the conservation benefits are recognized. Water reclamation occurs principally as a by-product of water pollution control programs.

Water reuse involves conflicts in need, risk, and economics. There are no mechanisms in the U.S. for resolving these conflicts except the excruciatingly slow process of evolution. It appears that the decision to reuse wastewater eventually will be made by the public in response to a great need.

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Work Group Report
Ground-Water Recharge

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REPORT

OF THE

GROUNDWATER

RECHARGE WORKSHOP

OBJECTIVES

To evaluate the role of groundwater recharge in providing water suitable for potable reuse as well as other types of reuse, to summarize our knowledge regarding water quality changes during groundwater recharge as pertains to potable and other types of reuse, to consider the alternative techniques for groundwater recharge and to identify the factors that influence performance, to assess our ability to formulate rational standards for reuse, and to identify research needs.

WATER QUALITY TRANSFORMATIONS AND BENEFITS

Important benefits can be obtained by groundwater recharge. An economical means of transportation is provided, while losses and mineralization resulting from evapotranspiration are reduced. In addition, some contaminants are removed from the water and the movement of others is retarded by passage through the subsurface environment.

In the following, the current state of knowledge regarding transport and transformations of contaminants is summarized. It is possible to assess the transport and transformations of some, but not all, contaminants that must be considered.

Inorganic Ions

Although the major cations and anions (Ca, Mg, Na, Cl, SO_4, HCO_3) are not removed during passage through the unsaturated or saturated zones during recharge, adequate research and field experience show that they essentially move with the water; their movement is therefor predictable.

Nitrogenous contaminants are somewhat more complex in terms of their transformations than are the major ions. The nitrogen species can be transformed, depending on redox conditions and the presence of the appropriate bacteria. Experience shows that nitrogen in the subsurface usually is in the form of ammonia, nitrite, or nitrate. These can be lost to the atmosphere by denitrification, retained by sorption in the soil matrix as ammonia, or be transported in the aqueous phase as nitrate. Nitrite is a transient state that is seldom observed in groundwater.

Phosphorus is removed from recharged waters by chemical precipitation at proper pH in the presence of appropriate cations, usually aluminum, iron, or calcium. Although this process requires some time and distance of travel, phosphorus is seldom of concern in the subsurface environment.

Organic Contaminants

Quantitative information on the behavior of many toxic or potentially toxic organic solutes is lacking, although considerable information has been gained on the behavior of a few compounds or classes of compounds.

The following principles are thought to govern the interactions of organic solutes in the soil and aquifer environments and to influence their transport. Poorly soluble, hydrophobic organic solutes tend to partition (sorb) onto the organic component of the solid medium, hence retarding their transport. The magnitude of this effect can be estimated using the octanol-water partition test. Low molecular weight, highly polar, and anionic organic compounds tend to remain in, and move with, the aqueous phase. Microbial degradation of some organic solutes can be significant, especially in the unsaturated zone or aerobic waters. Anaerobic degradation can also occur with some compounds, usually at a slower rate than aerobic processes. Some toxic organics, such as kepone, apparently do not degrade at all. Most biodegradation appears to take place near the point of input.

In the following areas, our knowledge is insufficient to permit us to predict the fate of organic contaminants in groundwater. Specific information on degradability and sorbability of most organic compounds of potential concern is lacking. There is virtually no information on slow, long-term biodegradation of organic solutes under subsurface conditions. There has been inadequate confirmation of laboratory studies by field observations. Data on the effects and rates of other reactions such as hydrolysis are lacking. Effects of chlorination and other disinfection techniques on the organic solutes in groundwater are poorly understood. The nature and behavior of biodegradation products are unknown.

Metals

An impressive body of knowledge has been developed on the equilibrium chemical behavior of some metals in water, such as iron, aluminum, and manganese. The effects of Eh, pH, ionic strength, and temperature on major metals such as iron, aluminum and manganese are well understood. The ion exchange properties of highly ionic stable cations such as Ca^{2+}, Sr^{2+}, and Na^{+} also are well known.

However, questions remain on some aspects of metal transport in groundwater, particularly for trace metals. These unknowns include:

formation and behavior of organo-metallic complex compounds, especially those of trace heavy metals; biodegradation effects on organo-metallic compounds, behavior of inorganic metallic complex anions, such as chromate and arsenate; the role of organic complexing agents in the mobility of trace metals; and sorption or ion exchange properties of some trace metals..

Particulates and Pathogens

Particulate matter contained in the recharge water is generally of a size amenable to removal by filtration or sorption within relatively small distances from the point of recharge when the project is properly designed, constructed, and operated.

Based on field and laboratory data, it appears that substantial reductions in numbers of microbial pathogens occur during recharge through granular deposits of mixed grain size and mineralogy. A combination of filtration and sorption is believed to be the mechanism of removal. The effectiveness of removal is dependent on the nature of the soil and of the microorganism. Pathogen survival is dependent on temperature. Viruses are not permanently immobilized on soil particles; sudden changes in flow velocity or water quality can mobilize previously sorbed viruses. This can result in the chromatographic movement of viruses through the soil. The factors that influence travel distance and survival time of viruses in the subsurface are not completely understood. Nonetheless, it is believed that complete pathogen removal should be achievable, given sufficient travel distance and retention time.

RECHARGE PRACTICES

Types of Recharge

The major types of groundwater recharge are well injection, infiltration from surface spreading basins, and river bank filtration. The major advantages and disadvantages of each are as follows:

Well Injection -- The major advantages are that the recharged water can be introduced into a designated aquifer, it is protected from casual insults, the injection rate can be controlled by varying the pressure, and there are no evapotranspiration losses. The major disadvantages are clogging of the screen and/or aquifer; higher required level of pretreatment compared to surface spreading; higher capital, energy, and maintenance expenditures; and absence of water quality benefits that may result from percolation through the unsaturated zone.

Infiltration from the Surface -- The major advantages are: enhanced water quality improvements due to biodegradation and volatilization in the unsaturated zone; lower cost than direct injection, unless land costs are extremely high; possible dual use for recreation if suitable pretreatment is applied; lack of clogging problems; and inherent capacity for storage and equalization. Disadvantages are: large land area required; infeasibility where barriers to vertical percolationexist; and possible water quality degradation during surface storage.

River Bank Filtration -- Bank filtration essentially is a filtration treatment technique for contaminated surface water, intended to augment well yield. Typically, groundwater quality is influenced only over short distances (< 1 km.). The special conditions that must be met and the limited areal impact exclude river bank filtration from consideration in most recharge situations.

Unsaturated Zone

The essential difference between the direct injection and percolation approaches lies in the passage through the unsaturated zone, which is a feature of the latter approach but not the former. It is generally believed that passage through the unsaturated zone affords greater water quality benefits than does saturated zone passage, expecially with regard to biodegradation. However, these benefits are specific to both the water composition and the site's soil characteristics. In general, there is an inverse relation between the hydraulic capacity and the treatment potential of a recharge site: coarse-grained soils can accept a high hydraulic loading but achieve less treatment than do fine-grained soils. Direct assessment of soils at a proposed site is necessary.

Water Quality Considerations

Water characteristics that influence recharge decisions are:

1. Physical Characteristics
    - Suspended solids content
    - Temperature
    - Color
2. Chemical Characteristics
    - Hazardous organic chemicals, including byproducts of chlorination.
    - Nitrogen species
    - Metals
    - Organometallics

In addition, byproducts of transformations that occur during recharge must be considered: nitrate from biological nitrification, carbon dioxide and methane gas resulting from organic substrate utilization, and soluble decomposition products from organic compounds.

Recharge System Design

Site selection is the critical first step in planning. The soil type must be chosen to achieve the desired combination of hydraulic capacity and treatment effects. The depth to the water table should be sufficient to allow substantial passage through the unsaturated zone. The formation groundwater must be compatible in quality with the recharge water; otherwise pretreatment modifications are necessary to prevent unfavorable interactions such as chemical precipitation. Geological conditions should be sufficiently simple and well characterized to permit satisfactory prediction of the direction and velocity of recharged water's movement.

Major factors in recharge system design are: quality of recharged water (pretreatment); loading and injection rates; configuration of recharge and extraction sites; control of well pressure, as well as proper construction and sealing of wells and provision for well redevelopment, in the case of injection projects; choice of flooding/drying cycle times and maintenance of percolation capacity in the case of surface spreading; and quality objectives for the extracted water.

Dedicating a Sub-Basin to Artificial Recharge

The art of predicting groundwater movement is far from perfect. Nonetheless, the Groundwater Recharge Workshop Group is confident that, under suitable geological circumstances, recharge/extraction systems can be designed and operated so as to reliably contain the zone of influence of artificial recharge within a predetermined portion, or sub-basin, of an aquifer. This raises the possibility of dedicating a portion of an aquifer to groundwater recharge and nonpotable water reuse, while minimizing the potential impact on uncontrolled use in other portions of the aquifer. Under such a system, it would be possible to capitalize on the treatment benefits of soil/aquifer passage by recharging water of quality lower than that required at the extraction point, in confidence that existing use of the groundwater resource would not be jeopardized.

TREATMENT IMPLICATIONS

Assuming the existence of an appropriate management structure, decisions concerning the treatment of wastewater before, during, and after recharge must consider the following factors:

1. The geology and characteristics of the basin or aquifer media,
2. The physical arrangement of the extraction system,
3. The travel time and distance between points of recharge and extraction,
4. The source of the wastewater, and
5. The sources and relative quantities of other recharge waters.

If the combination of these factors indicates that pathogens will be removed effectively in the course of recharge, it would appear preferable to avoid disinfection prior to recharge. If there is a need to disinfect to protect the public from contact with the water prior to discharge or where disinfection is required to avoid biological clogging of injection wells, more research should be devoted to determining the disinfection process with the least tendency to form harmful products.

Because groundwater basins may receive undesirable or toxic organics from urban runoff or industrial spills, highly sophisticated processes like activated carbon and reverse osmosis should be considered for polishing treatment in order to assure that the water meets drinking water standards similar to those applied to drinking waters derived from surface waters.

Until toxicological studies indicate a better basis for monitoring or evaluating the health effects of trace organics in drinking water supplies, the criteria for recharge operations should be the same as the quality standards accepted for potable use of surface waters. Wastewaters should receive, as a minimum, secondary treatment prior to recharge by spreading, and high performance filtration and possibly chemical treatment prior to injection to avoid plugging. The location of other treatment processes prior to recharge or after withdrawal should be made on the basis of cost-effectiveness and reliability in meeting drinking water standards.

Generally, concentrations of inorganic chemicals will be within drinking water standards at the point of recharge, if source control and treatment are adequate. Trace organics which can be detected and identified and which are suspected to be toxic and to penetrate aquifers must be controlled or eliminated at their source to the extent possible. Because the toxic effects related to the standards for organic and inorganic constituents are based on long term exposures, the quality criteria at the point of recharge should be based on long term (1 year) averages.

In some cases, the management of a groundwater basin may permit its dedication to non-potable or to potable uses with the availability of an alternative potable supply. Under this condition, the management of the basin will permit a higher dependence on underground treatment, since the consequence of a contaminant breakthrough would not be as serious.

MONITORING IMPLICATIONS

Groundwater recharge projects using wastewater must have adequate monitoring programs. The quality of the recharge water, the groundwater, and the extracted water should be monitored, as a minimum, for major inorganic ions, heavy metals, organic chemicals, and microbiological pathogens and/or indicators. The specific items monitored will be those needed to determine whether or not the waters meet drinking water standards. In addition, there are some special monitoring needs for the groundwater systems, such as infiltration or injection rates and groundwater levels, to determine flow rates and direction of flow. The water quality characteristics of the groundwater should be evaluated by a monitoring program prior to project implementation. Monitoring of stream flow or other recharge contributions to the aquifer may be appropriate to evaluate resulting groundwater quality changes.

Are real-time, on-line monitoring systems available? They are for some of the items required by drinking water standards, but not for others. Such systems should be developed for those parameters for which they are not now available, or for appropriate surrogates. Nonetheless, groundwater recharge relieves substantially the urgency of real-time monitoring, by providing long residence times and large storage capacity, thus smoothing concentration fluctuations.

The management agency will monitor the quality of water extracted. If it is not acceptable according to drinking water standards, the management agency will provide the needed treatment to assure compliance, or will provide an alternative source of supply. Adjustments can be made in the treatment prior to recharge if appropriate. Monitoring to permit illustration of trends in quality is needed to allow system adjustments before quality standards are violated.

Monitoring programs must be properly designed to allow collection of the desired data. The point location of the sample, the sample collection technique, and the analytical methods are critical to any competent monitoring program. A major objective should be to trace the movement of recharged water and potential pollutants from the recharge point toward withdrawal points. Sampling location and collection methods are especially sensitive in groundwater quality measurement because the vertical and horizontal permeabilities can differ greatly. Monitoring points should be numerous close to recharge areas to obtain timely evaluations of potential quality changes.

It is recommended that EPA develop standardized monitoring techniques (location, sampling, and analysis) for use in groundwater recharge projects for potable reuse. This expressly implies that government-certified laboratories must conduct the required analyses.

CONCLUSIONS AND RECOMMENDATIONS

- Groundwater recharge for potable reuse is encouraged when the quality of the recharge water meets drinking water standards in every respect.

- With respect to the transport and transformation of contaminants in the subsurface environment, the Committee believes that the following table summarizes the current state-of-knowledge with respect to the ability to predict impacts of groundwater recharge projects in such a way as to protect the resource for future use.

Contaminant Class	Adequate Knowledge	
	Yes	No
Major cations and anions	X	
Particulates	X	
Nutrients (N & P)	X	
Metals	(X)	
Organics		(X)
Microbiological pathogens		
bacteria and protozoa	(X)	
viruses		(X)

where the enclosing parentheses indicate that the categorization is especially subject to uncertainty.

- Important benefits can be obtained by groundwater recharge. In addition to providing an economical means of storage with reduced evapotranspiration, subsurface passage removes some contaminants and retards the movement of others, by means of filtration, biodegradation, volatilization, sorption, chemical precipitation, and ion exchange.

-- A combination of pre-recharge treatment and natural groundwater basin treatment can be used to minimize the need for treatment after extraction and to assure that the water quality at the point of reuse reliably satisfies current and forseeable drinking water standards.

-- When water considered for recharge contains certain classes of contaminants, the behavior of which in the subsurface environment is not adequately understood, the materials must be removed by treatment before recharge. Exceptions should be permitted where the water is to be applied to a groundwater basin dedicated for research or demonstration purposes.

-- Groundwater recharge with water subject to contamination should be practiced only if there is effective management control of withdrawals in the affected hydrologic area.

-- All groundwater recharge projects must be adequately monitored to confirm performance within appropriate design criteria and standards.

-- Geological media containing secondary permeability features such as fractures or solution cavities cannot be relied upon to provide subsurface treatment.

-- Research is needed to understand the processes that influence the fate and movement of contaminants in the subsurface environment and those characteristics of that environment that affect contaminant movement.

-- Information on all aspects of potable reuse of reclaimed water should be made widely available. The existing AWWA Water Reuse Clearinghouse should be strengthened and expanded to fulfill this need. The assistance of the Public Participation and Reuse Subgroups of the National Drinking Water Advisory Council should be solicited.

Work Group Report/Issues Paper

Non-Potable Reuse Options

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WORK GROUP REPORT

NON-POTABLE REUSE OPTIONS

Introduction

In the U.S. there are now more than 500 successful projects using treated municipal wastewaters for a myriad of non-potable purposes whereas there is only one pilot plant treating wastewater for potential direct potable reuse now in operation.

Non-Potable Reuse

Non-potable reuse will be an increasingly important part of the nation's water supply. Such reuse:

1. Relieves the demand on limited high quality sources of water, permitting these sources to be used for potable purposes by growing populations.

2. Generally will cost less and is less energy intensive than developing additional high quality water sources, where these are available, and will likely cost less than direct potable reuse, even where such reuse is feasible.

3. Eliminates the need, in most applications, for extensive monitoring of trace contaminants and costly toxicological and epidemiological studies, while assuring consumers freedom from these contaminants in their drinking water.

4. Generally eliminates the need for the removal of nutrients that are valuable in non-potable applications for irrigation.

Accordingly, far more attention needs to be given to the various aspects of nonpotable reuse. Nonpotable reuse has developed, and will continue to develop in stages. The earliest non-potable applications involved using conventional wastewater treatment plant effluents for industrial water supply within a single industry. This was expanded to include service to large users, with higher quality requirements. Finally, non-potable reuse evolved into service for a wide variety of customers throughout a community, thereby often requiring dual distribution systems and exceedingly stringent quality requirements so that exposure or contact would not constitute a health hazard. Eventually, if a clear need for direct potable reuse should develop in a community, that need would be expected to be the ultimate stage of development, building upon the direct non-potable reuse experience.

Research on direct potable reuse should be lower in priority than non-potable reuse in level of investment. However, this does not mean that research into monitoring, treatment technology and health effects for potable reuse are not of pressing urgency. Such research should be actively pursued in many locations throughout the U.S. where indirect potable reuse (the withdrawal of water for potable purposes from rivers that receive substantial contributions of municipal and industrial wastewaters) is now exposing millions of people to trace contaminants. The deliberations of this meeting on Protocol Development: Criteria and Standards for Potable Reuse, organized as it is with panels on chemistry, microbiology, toxicology and engineering, are profitably directed at the critical need for better management and understanding of potable reuse now being practiced.

Potable Reuse

Potable reuse is not likely to evolve as a practical option in the immediate future for a variety of reasons:

1. Sources of better quality than wastewater that are economically available, or other options for meeting the water supply needs of a community, will be more attractive than direct potable water reuse.

2. The public may have aesthetic reservations about ingesting water drawn from their own wastes, particularly where other options are available. The most direct answer to these issues is to supplement the existing water supplies by judicious use of non-potable options such as industrial uses, cooling water and irrigation.

3. Wastewaters, even from communities without intensive industrialization can be expected to have many trace contaminants of potential health significance. Moreover, because potable reuse inevitably requires sophisticated technology for monitoring and treatment, it would be appropriate only in large cities which would inevitably contribute industrial wastewaters to the system.

4. Monitoring and removal of trace contaminants in municipal wastewaters is expensive in instrumentation, facilities and personnel and requires extensive redundancy to provide adequate

safety.

5. Establishing criteria for safety presents many problems. Maximum contaminant levels (MCLs) are difficult to establish for any single chemical and virtually impossible for mixtures of chemicals. As more is learned about the chemicals in wastewaters MCLs will most probably be lowered and new MCL's will be added.

6. Communities embarking upon potable reuse programs would have to conduct extensive research as results obtained in one location are not likely to be applicable to another.

Given the low potential for any significant direct potable water reuse, far more attention needs to be given to studies and stimulation of non-potable reuse. The national investment in clean water projects has provided the basis for non-potable reuse projects in many areas.

Conclusions

1. Water reuse is mandated by the Clean Water Act. See:

(a) Title I - Research and Related Programs Section 105 - Grants for Research and Development (d) (2), which requires methods for reclaiming and recycling water to be included in the grant.

(b) Title II - Grants for Construction of Treatment Works Section 201 - Purpose (g) (2) (B), which requires application of technology to provide for reclaiming or recycling of water.

Section 214 - Public Information, which requires a continuing program of public information on recycling and reuse of wastewater.

2. Non-potable reuse is practicable and appropriate from a water resources management standpoint. In many instances availability of low quality waters will permit the use of municipal wastewater for lower quality reuse applications. The lower quality applications, will invariably require a lesser quality water than potable reuse. This lower quality requirement will generally result in a simpler treatment system along with its associated lower capital and operation and maintenance costs and lower energy requirements. A potable reuse treatment system might typically consist of up to ten or more unit processes or unit operations such as primary sedimentation, biological reactor, secondary sedimentation, chemical clarification, recarbonation, multi-media filtration, selective ion exchange, breakpoint chlorination, carbon absorption, reverse osmosis and disinfection along with ancillary operations such as recalcining and carbon regeneration. In contrast a non-potable irrigation alternative might only require two-stage aerated ponds, disinfection and the necessary distribution system. Additionally, non-potable options could be expected to encounter less resistance in public acceptance.

3. There is little or no consistency between and among the Federal agencies in their approach to non-potable reuse issues.

A critical need in promoting reuse of industrial wastewater in the food processing industry is the development of the required scientific and technical knowledge for better coordination between the Environmental Protection Agency, Food and Drug Administration, Occupational Safety and Health Administration, and the U.S. Department of Agriculture to develop a common set of guidelines or regulations. This may lead to a redrafting of some of the legislation or agency regulations dealing with the general use of water in food plants and in particular with the definition of the term "potable", where used.

In addition to similar regulations, a common permitting process or person would facilitate water recycle projects in the food industry. Increased support by the government and by the food industry should be provided for research and demonstration projects into complete water recyling. Attention should be directed to the characteristics of unit process effluents and the desired quality of water to be recycled in that unit process. Reuse of such unit effluents will result in increased product yields, opportunities for by-product recovery, and more efficient use of energy in heated and cooled effluents. Rather than one set of non-potable water standards, reason and the logic of science applied to case-by-case situations is needed to guide these reuse potentials.

The non-degradation and zero discharge policies of the EPA create an artificial impediment to increased reuse and the Agency needs to clarify its position in this regard. Federal and state pollution control laws prohibit the discharge of pollutants in an amount that would cause a signifcant deterioration of existing environmental quality.

Guidance is needed to promote uniform interpretation of the term "non-degradation". Non-degradation should be interpreted within the entire context of a particular law, giving due weight to other important provisions including, in the case of the Clean Water Act, those provisions that promote reuse of wastewaters. For instance, if non-degradation is used to prevent any deterioration in water quality, then non-degradation becomes a formidable obstacle to many beneficial uses of wastewater. On the other hand, if the prohibition against significant degradation is viewed as permitting some deterioration in quality so long as existing opportunities for beneficial uses of the water are not impaired, then the methods are available to promote beneficial reuses of wastewater in keeping with the overall intent of this law.

5. As industrial water consumption in the U.S. significantly exceeds domestic water consumption, incentives for reuse/recycle by industry will have a much greater impact upon conserving our water resources than will other types of reuse programs.

- The two broad categories of industrial reuse are:
  - Reuse of treated municipal wastewater effluents by industrial facilities.

- Recycle of industrial wastewaters within the industrial facility itself.

- It is generally accepted that the following are "known" facts pertaining to industrial reuse:
  - The general public accepts wastewater reuse/recycle by industry with the possible exception of the food processing and pharmaceutical industries.
  - Industry will reuse/recycle wastewaters to the maximum extent that it is (1) economically advantageous to do so, (2) technically feasible without adverse effects upon their processes and products, (3) aesthetically acceptable to their workers, and (4) not in violation of federal and other applicable regulations.
- Industry is relatively conservative in accepting changes in the quality of their water supply, both overall and for individual processes. There must be clear documentation and assurance that the economic benefits outweigh any perceived disadvantages.
- Companies within the same industry are in competition, and do not necessarily "share" technological improvements such as improved recycle methods with competitors.
- Cost of fresh water, availability/reliability of fresh water supply, and cost of wastewater treatment/disposal

are the principal driving forces encouraging industrial reuse/recycle.

- Under the "zero discharge" goal of existing legislation, the EPA probably has the tools to encourage industries to achieve optimum water recycle with corresponding minimum volume of final wastewater discharge volumes.
- In terms of potential volume for reuse, the recycle of industrial wastewater within industrial facilities far exceeds the volume of treated municipal wastewater which can potentially be reused by industry.
- While certain similar water using processes, e.g., cooling towers, are common to many industries, most unit processes are industry specific. It is generally necessary, therefore, to consider reuse/recycle potential separately for each major industry, e.g., textiles, chemical manufacture, pulp and paper, etc.
- The effluent guideline studies conducted by EPA clearly show great differences in the volume of wastewater generated per unit of production (e.g., tons of steel) between different individual plants in the same industry. Ranges of 5:1 were not unusual. While other factors (e.g., age of plant and equipment) influence this wide disparity, the single dominant factor is the extent of in-plant water recycling practiced.

Suggested Actions

From a water resources conservation perspective, the nation can get the most benefit for its research and regulatory dollar by overcoming economic, technical, and regulatory inhibitions to industrial reuse/recycle.

Possible actions include the following:

1. Implementation of engineering studies and demonstrations which provide solid, defensible, documented and detailed methods for optimum water recycle within each of the major water using industries. The program must have industry support and cooperation from planning through technology dissemination. All important technical, economic, aesthetic, regulatory, and institutional factors must be determined. Federal Agencies are initiating some studies in some of these high water use industries.

2. Such studies will be helpful to both industry and government in providing reliable information pertinent to feasible water use/wastewater volume discharge per unit of production. Financial incentives and disincentives can be evaluated. These studies should be accomplished at the lowest feasible level, i.e., Regional or State, to take into account the available water resources in the local areas.

3. Optimum recycling concentrates pollutants into a smaller volume of wastewater. Consideration must be given to the mass pollutant discharge, not concentration limits, in regulating effluents.

4. Wastewater can be a highly useful component of a water resource system that includes a minimum streamflow goal. In that case, salvaged wastewater delivered in the right quality at the right place might be the highest and best use of that source of water. At little or no additional cost it provides an acceptable substitute for run of the river water and thereby reduces the frequency and extent of water rationing to protect instream uses. Since this is a non-potable reuse of wastewater, criteria and standards for water quality should be selected to enhance fish and other aquatic life and produce the desired environmental effects.

Recommendations

EPA in cooperation with other federal agencies, professional groups, States and interested local groups should prepare guidelines for the significant technical, economic, and health issues affecting non-potable reuse.

a. A manual of current practice should be developed based upon existing work by federal agencies, the State of California and other groups to include the design, operation and maintenance of reuse systems.

b. Consistent and comprehensive public health guidance should be provided for categories of non-potable reuse:

- irrigation
- recreational
- cooling

- industrial
- groundwater recharge
- stream augmentation
- urban reuse
- aquaculture
- other

c. Comprehensive information on the economics and financing of reuse systems should be prepared and disseminated.

Non-potable reuse can be used instead of conventional supplies (as opposed to situations where water cannot be supplied except by reuse). In many of these cases, reuse directly benefits neither the reclaimer (wastewater agency) or the reuser (water agency or industry). The reclaimed water may be more expensive to produce and use than alternative conventional supplies and is typically of lower quality. In these cases, significant benefits can accrue to neither the reclaimer or the reuser. They accrue to streams that would not be dammed, or to other agencies that would use the conventional supplies replaced by reuse, or to agencies whose costs of operation of import projects would be reduced.

If these benefits cannot be converted into dollar form and used to offset local costs, the local agencies may not have adequate incentive to carry out the reuse project.

In these cases, the "real benefits" should be identified and a financing mechanism must be developed; otherwise, the reuse project may not be carried out.

The Guide should cover the project cost elements, including advanced treatment consistent with health and technical requirements; delivery system elements such as pipelines, pumps, and storage; on-site costs including the customer's service connection, replumbing, and backflow prevention. These costs should reflect special operation considerations such as overwatering to control the salinity of irrigated soils and needs for additional chemical additives to cooling towers.

The economic section should cover the full range of typical project benefits, including benefits which fall outside the project area. In general, project benefits may be estimated classically in terms of the least cost-feasible alternative, using marginal or opportunity costs where appropriate.

There are numerous financial and economic issues which are beyond the scope of this summary report. However, a few topics worthy of mention have been raised by workshop participants based upon their current experience in new program development.

These are discussed here as special consideration in project finance.

Beneficiaries. Under an ideal financing plan, water reuse project costs will be paid by those who benefit. In some cases, the beneficiaries are the customers, in which case, the financing plan is mainly concerned with setting a customer pricing structure which returns project costs and provides for a sound operating and maintenance program. In other cases, however, project finance is complicated by the following factors:

- Water reuse benefits accrue outside the project area.
- The competing fresh water supply is subsidized or operated under "rolled in" rate structures.

Either of these factors can effectively block the development of a water reuse project, even though the project is economical compared to the next best alternative, such as fresh water impoundment and diversion. Whenever the fresh water supply to an area is not developed regionally, or at the state or federal levels, water reuse benefits may fall outside the project area. This is because the reuse project customers are reducing their demand on the fresh water supply, thereby releasing fresh water to others in the region or state for general domestic use. In other words, water reuse becomes a regional supply increment. In such cases, the most effective financing plan should also be based regionally, in order to recover costs from the beneficiaries.

- Financial Methods to Capture External Benefits. Where a substantial portion of project benefits accrue to the region or state, there are two basic approaches to capital financing:
    - ° Utility Financing: Reuse projects are financed by a regional or state water utility on the same merit basis as the freshwater alternative.

- Grant Financing: Direct grants or other subsidies from the region, state or federal government to local implementation based upon an acceptable demonstration of economic benefits.

Grants or loan assistance may be necessary to encourage types of non-potable reuse that cannot be easily financed using the utility concept, particularly innovative uses of reclaimed water. Utility financing, which is the more difficult to establish because of the need for new legal and administrative arrangements, has the advantages of:

(1) Ensuring a least cost regional water development program which incorporates all of the fresh water and reuse options impartially based on merit.

(2) Providing a greater incentive for a quality and maintenance program because the reuse project is an integral part of the utility, rather than an add-on built with government monies.

d. Federal, State, and local agencies should develop a strategy for reuse that adequately addresses all the necessary institutional issues.

In summary:

Water resource planning should consider the use of municipal wastewaters. Water conservation is also significant but both subjects are considered beyond the scope of the meeting. Evaluating the appropriate uses of municipal wastewater, it is clear that non-potable use provides the greatest potential for large volume reuse and will be attractive and cost-effective since quality standards will be less demanding, and costs in terms of money and energy will be less. In addition, for many types of non-potable reuse, quality standards are already in use.

Clear-cut guidance in the form of engineering design criteria and for water quality parameters should be developed and enunciated for the whole range of non-potable reuse.

A pressing need, in addition, is to develop the necessary scientific base for standards for water supply now drawn from polluted sources. This is the potable use to which the rest of this meeting should be directed.

7/1/80

ISSUES PAPER FOR

EPA Symposium on Protocol Development:
Criteria and Standards
for Potable Water Reuse and Feasible Alternatives

Evaluation Protocol:
Non-Potable Options for
Meeting Urban Water Needs

By

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This issues paper is to provide the basis for workshop discussions on non-potable reuse options. To provide a framework for the discussion, the following should be considered:

- Wastewater as an integral part of our water resource system which requires efficient planning and management.

- Conceptual and practical problems in developing separate criteria and standards for potable and non-potable reuse.

- A variety of state and federal laws which deal in limited ways with this subject.

- Work of the potable reuse panels which must be considered in the evaluation of non-potable alternatives.

The objective of the workshop is to assist EPA in considering reuse when it carries out its statutory responsibilities. The purpose of this issues paper is to provide a framework for evaluating non-potable reuse and indicate the types of reuse criteria that are needed. If significant quantities of wastewater are to be reused, a national perspective is needed. It is provided in "Water Reuse and Recycling--Evaluation of Needs and Potential", authored by

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Culp/Wesner/Culp and published by the Office of Water Research and Technology in April 1979. Workshop participants are urged to refer to Volume 1 of this work for national and regional statistics on water use, availability, and the production, reuse, and recycling of wastewaters.

Ideally, a single set of criteria and standards governing the selection, design, and operation of water supplies could be established to provide adequate public health and environmental protection recognizing economic factors. Conditions are constantly changing: our knowledge of public health effects and the behavior of chemicals in the environment is expanding and will continue to expand at a rapid rate; real understanding of environmental effects is replacing the recent wealth of conjecture; and the time factors and costs of resource management and development are steadily increasing. Recognizing these facts, reuse criteria should include statements of principles and procedures as well as numerical objectives. One need only to consider the arguments over established standards such as barium, fluoride, asbestos--and, of course, trihalomethanes--to realize that the establishment of standards per se is not a sufficient basis for the development and operation of water reuse projects.

Our attempts to reach agreement on reuse issues are further hampered by differing or arbitrary definitions of the terms "potable", "non-potable", "direct", and "indirect", and conflicting meanings assigned to "reclamation", "recycle", and "reuse".

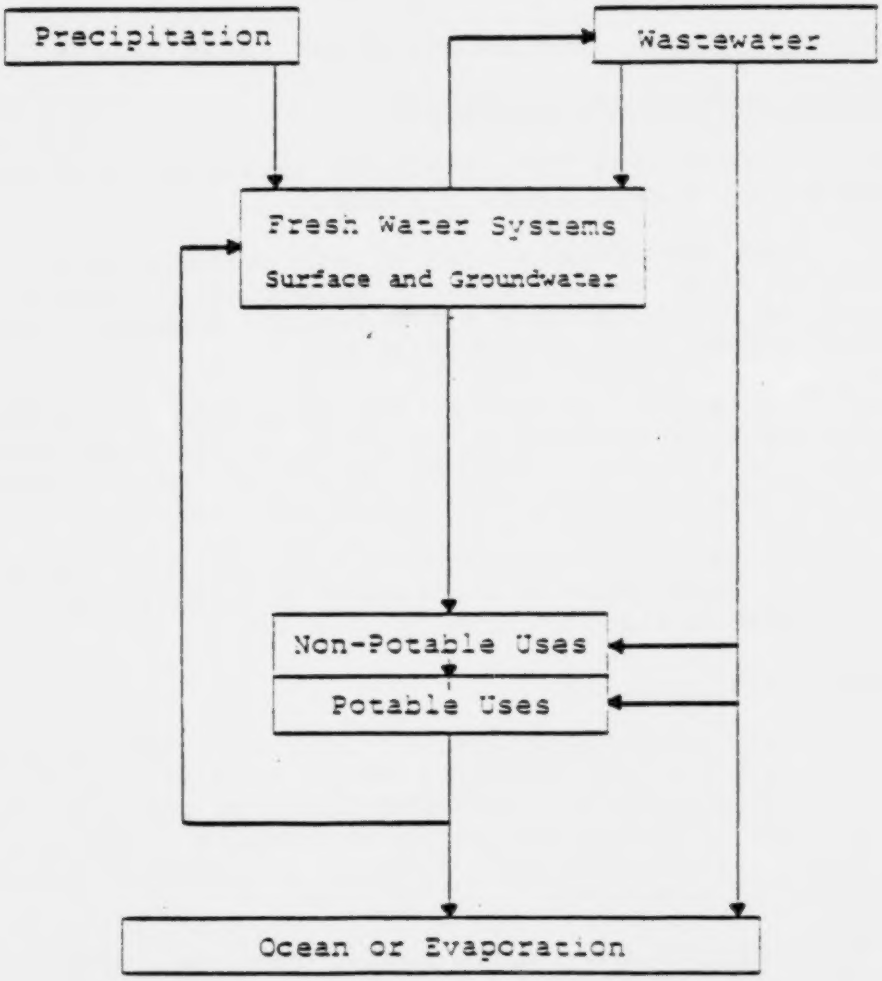
Most of the other symposium workshops have subjects which can be more narrowly addressed. Our subject could be addressed in a technical discussion of the economic, health, and environmental criteria or standards associated with a list of specific "non-potable" uses. However, due to the background of the participants and the nature of the symposium, we will try to establish some concepts for criteria and standards and recommend an approach to the evaluation of reuse projects that will, hopefully, aid in making more efficient and safe use of our water resources. The following key concepts may be self-evident, but I believe they are important in forming a sound foundation for reuse criteria and standards.

INITIAL CONCEPTS

Effective criteria and standards depend on general acceptance of basic concepts including definitions, relationships (such as potable and non-potable reuse), and water supply needs. Figure 1 shows some reuse relationships in a simplified water cycle diagram.

FIGURE 1

NEW AND USED WATER CYCLE



Definitions

The following distinctions are suggested for planning purposes:

Potable Reuse. Use of a drinking water supply that is planned and operated to rely upon a specific controlled wastewater source.

Non-potable Reuse. Use of all other supplies that are planned and operated to rely upon specific controlled wastewater sources.

Direct Reuse. Use of a continuously controlled, limited storage and conduit connection between a wastewater source and a use.

Indirect Reuse. Use of all other reuse delivery systems.

Potable/Non-Potable Relationships

1. Potable uses can rarely be separated from non-potable uses, except in direct reuse systems.

2. Most non-potable uses affect potable uses. Examples are: agricultural return flows, industrial process discharges, drainage from urban landscape irrigation, seepage from recreational lakes, and stream flow augmentation.

3. The health, economic, and environmental effects of potable and non-potable reuse depend, in part, on the time period before use, amount of dilution, and the nature of the conveyance system from the reclamation facility to the point of use.

4. All reuse affects potable uses to some degree unless the ultimate user evaporates the effluent or discharges it to the ocean or other unusable supply.

Water Resources Planning

Given these relationships, it is clear that setting comprehensive numerical criteria would be a monumental task. Also, without definition of all technological and physical factors, they cannot be used to fully define an acceptable reuse situation. Widespread reuse will depend upon a logical framework for comprehensive water resources planning.

Water supply plans at the state, regional, and utility levels should identify the quantities needed to meet anticipated needs. This should include ranges of demands based on growth, economic, and unit use assumptions for domestic, industrial, agricultural, and other use categories. Diluted and undiluted wastewaters should be considered a part of the water resources that are available to meet supply needs.

Except in a general way, it is frequently not possible to draw a clear distinction between potable and non-potable uses, or between direct and indirect uses. Planning for reuse requires an evaluation of each source and its contribution to the total supply that is available to satisfy each potential use category.

Many existing reuse projects are operated to meet specific needs that occur near an existing source of reclaimed water. However, projects to reuse significant quantities of water cannot be adequately justified unless they are compared with alternative projects to supply the projected or existing use. It should be noted that this paper is directed toward reuse as a significant component of areawide, regional, or national water supplies. In localized and controlled situations such as military or institutional water supplies, there is much greater opportunity for developing a secure and reliable set of numerical reuse criteria, while in a less controlled situation such criteria could be inadequate.

Management Authorities

Existing laws and regulations designed to solve specific water problems often impede development of effective plans for reuse, thus:

- Development of potable water reuse criteria is mandated by the Safe Drinking Water Act without reference to water resource considerations.

- Health effects of effluents are major factors in setting water quality criteria under the Clean Water Act without reference to water supply treatment or dilution.

- State and federal water project development requirements and subsidies vary widely, despite considerable improvement resulting from the work of the Water Resources Council.

- State water rights priorities do not adequately consider return flows.

With some exceptions, treated wastewaters are managed by institutions that are not responsible for water supply planning. Also, with some exceptions, statewide and watershed water resources plans have not considered wastewaters as part of the range of sources available to meet future needs.

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EVALUATION APPROACH

The following evaluation approach together with selected numerical criteria can provide an adequate basis upon which reuse projects can proceed. The argument over a "single standard" diverts attention from the need for a standardized, broader evaluation system for considering water reuse. Advocates of reuse to meet potable needs (as a percentage of total supply blended either with surface or groundwaters) have desired specific numerical limitations for each constituent that may be harmful. The objective would be to design a treatment train to meet all standards no matter how stringent. Such a train, however, must have reliability and factors of safety that would be specified as treatment technology by the regulatory agency (California Code, Title 22, as an example). Furthermore, a set of numerical criteria (for instance, including viruses, synthetic organics, and trace metals) would inevitably lead to a treatment train that is most expensive and not one that would be selected if there were a balanced approach to project selection that considered all of the benefits and detriments.

Many regulators see the concept of a single standard as the forerunner of direct potable reuse. Such systems may be theoretically possible, but even in the few areas of the world where direct potable reuse is practiced, there are factors of safety provided by storage or other means that are deemed adequate to assure public health protection. The argument boils down to a matter of degree. The need for water must overcome the health risk which may be difficult to define.

Historically, some non-potable reuse criteria have evolved in relation to the specific proposed uses with due respect being given to the types and duration of exposure. The publication "Water Quality Criteria--1972" (EPA R3-73-033, March 1973) provides pertinent examples including criteria for irrigation water and for wastewater reuse for irrigation. Further, many states (California, Arizona, Maryland, Colorado, Georgia, etc.) have developed similar guidance for the reuse of wastewaters to irrigate croplands.

Related Federal Planning

The guidelines of the Water Resources Council, which provide the basis of evaluation of federal water development projects, are complex but provide essentially for a comprehensive view of all alternatives designed to meet projected needs. EPA's PL 92-500 Construction Grants Planning Guidelines provide for a similar type of analysis, particularly when coupled with the requirements of the National Environmental Policy Act. Planners and engineers have developed a variety of imaginative methods that can help government and elected officials to make decisions on public investments.

The expenditures under the Clean Water Act, now in excess of $30 billion, exclusive of local contributions, allow us to consider planned wastewater reuse, not just incidental reuse that takes place following discharge. In water-short areas, incremental costs and public health environmental risks are studied for each situation. The advantages of reuse are similar to the advantages of water conservation; investments in the construction of new water development facilities can be deferred and groundwater levels and stream flows can remain at higher levels since additional diversions or pumping may be avoided.

Comparative Ranking of Sources

All alternative sources, including reclaimed wastewater, should be evaluated using consistent procedures to develop comparative rankings. The factors that should be considered are:

1. Quality Effects of Alternative Sources. The quality of wastewater, in terms of dissolved solids and particular constituents, affects its usefulness for various purposes. The economic and non-economic effects of various qualities should be compared. Economic effects may include long-term reduction in usefulness of a groundwater basin which currently may be protected under the non-degradation provisions of water quality regulations.

2. Costs Including Energy Use. Capital, operating, and maintenance costs ("life cycle costs") must be developed for each source. This includes an assessment of energy use in production, transport, and treatment. With the recent several-fold increase in energy costs and further increases to come, the application of high levels of treatment technology for wastewater reuse is becoming uneconomical, except in special cases. Therefore, the initial emphasis for descriptive and numerical criteria should be primarily directed toward the following reuse categories: land application of wastewaters for the production of commercial crops, urban landscape irrigation, power plant cooling and industrial processes. In some areas, groundwater recharge and stream flow augmentation will be appropriate.

3. Range of Public Health Effects. Health effects and risk levels could be determined for each category of use, as follows:

- Ingestion--short-term and long-term, direct and indirect, intentional and accidental.

- Body contact--short-term, long-term, and accidental.
- Inhalation--short-term, long-term, and accidental.

Various risk levels could be compared with attainability since public health and environmental protection are not absolute. Standards should reflect costs and benefits of various levels of protection. This objective may not be realizable today. Public and corresponding legislative concerns about toxic substances will be heavily on the side of a "no health risk" policy for reuse--even when alternative supplies may carry significant health risks.

4. Ability of Source to Meet Reliability Requirements. Assessment of quality variations with time is important. Many industrial processes are particularly affected by quality changes. Some sources have a high risk of accidental or periodic contamination resulting from human error or equipment malfunction. Safety features to protect public health will vary for each source.

5. Short-term and Long-term Environmental Effects. The environmental effects of alternative source production and treatment and the effects of use of alternative sources should be evaluated in order to quantify significant differences.

Evaluation Systems

There is a sequence of analyses that can be used to evaluate the benefits and costs of reuse projects. The following diagrams describe an evaluation of reuse options within the context of water resources planning and based on existing institutional arrangements

Figure 2 shows a water supply and reuse planning hierarchy. Present planning programs are not so neatly organized, but they provide these elements in most areas of the country.

Figure 3 shows a framework for developing and applying the needed federal and state criteria for the evaluation of water resources projects. Criteria for each of the categories listed and perhaps others would provide a framework for reuse project analysis.

Figure 4 shows the steps in planning and evaluating methods of meeting state, interstate, or regional water needs.

Information from the preceding activities should then be used by local utilities. A local plan (similar to Figure 4) would be prepared. Then the details of individual reuse projects would be determined. Potable and non-potable reuse projects should be methods of achieving lowest risk, the lowest cost system for water use.

FIGURE 2

WATER SUPPLY AND REUSE PLANNING HIERARCHY

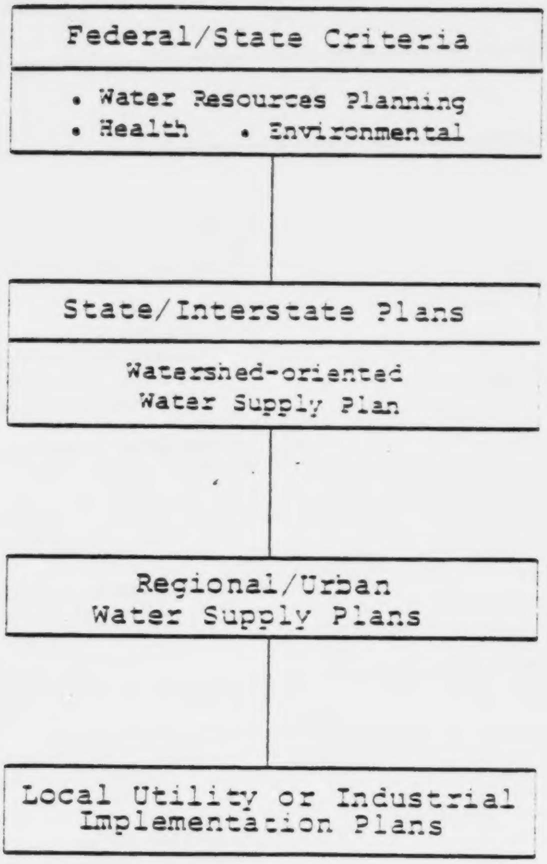

Federal/State Criteria
• Water Resources Planning
• Health
• Environmental
State/Interstate Plans
Watershed-oriented Water Supply Plan
Regional/Urban Water Supply Plans
Local Utility or Industrial Implementation Plans

FIGURE 3

FEDERAL AND STATE CRITERIA
FOR EVALUATION OF WATER REUSE

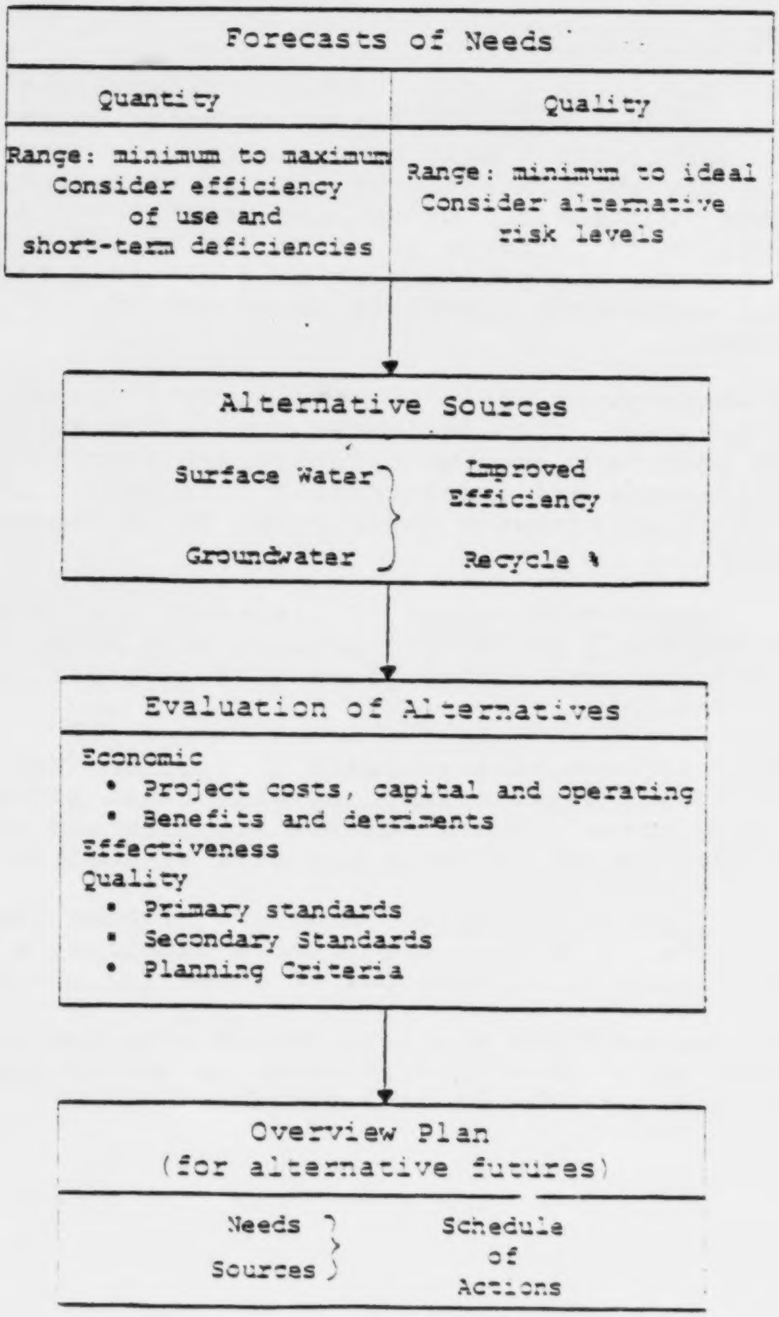
Factors	Criteria Needed[a]
Public Health	
a. Short-term exposure b. Long-term exposure	1. Numerical SDWA criteria by classes or individual constituents for desired level, acceptable level, and maximum acceptable level (10^4-10^6). 2. Descriptive criteria: a. Acceptable dilution to achieve numerical criteria. b. Elapsed time between wastewater treatment and reuse. c. Critical long-term supply factors and comparative costs of alternative supplies. 3. Circumstances affecting attainability not related to specific project.
Environmental	
a. Transient effects b. Long-term effects	1. Numerical water quality CWA criteria described as maximum concentrations for transient effects and ranges for long-term effects; national goals; minimum acceptable; attainability. 2. Circumstances affecting attainability not related to specific project.
Engineering/Economic	
a. Primary costs and benefits • Capital • Operation b. Secondary costs and benefits c. Local exceptions	1. WRC principles and standards and CWA 201 facilities planning procedures for reuse projects, individually and basin level. 2. Economic factors, particularly associated with total dissolve solids or metals. 3. Absence of viable alternatives or unique local conditions.

[a] Criteria needed for each category of reuse including: surface and groundwater augmentation, agricultural and landscape irrigation, and industrial process and cooling uses.

FIGURE 4

STEPS IN PLANNING AND EVALUATION
FOR WATER SUPPLY AND REUSE

(State, Interstate, and Regional)



The preceding discussion and diagrams are general and procedural. In some cases, it will be appropriate to bypass or modify some of the steps shown. Nevertheless, it should be a basic tenet of reuse project development and approval that it be done as part of an orderly water management system that is not based on a single set of fixed criteria.

APPLICATION TO SPECIFIC SITUATIONS

There is a number of types of reuse and hydrologic conditions that deserve special comment. They include:

Groundwater Augmentation

1. Dedicated Basins. Present federal and state policies tend to support a non-degradation approach to groundwater basin quality, particularly salt concentrations. When use of a basin or sub-basin can appropriately be limited to a single purpose such as irrigation, industrial, or cooling water supplies, it may be desirable to allow an increase in dissolved solids concentrations as part of a basin management plan that provides for recharge with municipal wastewater, drainage water return flows, and natural replenishment.

In water-short areas with adequate long-term supplies for potable purposes, such dedicated use may be appropriate provided that the long-term economic effects are thoroughly evaluated. The significance and importance of this dedication should be evaluated on an areawide basis prior to decisions on project development.

2. Basin Protection. Wastewaters are being reused to provide hydraulic protection against salt water intrusion into groundwater basins. Other protective uses include subsidence control, and dilution.

Reuse for groundwater basin protection that does not significantly affect potable supplies will be an increasingly important use in arid areas. Where potable supplies are affected, consideration of potable use criteria and risk evaluation is necessary.

3. Planned Recharge. Most groundwater basins in the country will continue to be used for potable supplies, although they may provide significant quantities of water for non-potable uses.

As long as there are alternative supplies that are economically available, recharge with wastewater in basins that have significant potable water use should be limited.

When research provides better data on basin performance and health risk, criteria should be developed to:

(1) Designate potable and non-potable basins.

(2) Reflect basin performance and potential health risks considering: minimum travel time and distance from recharge to extraction, basin biological activity, and acceptable percentages of "used" water.

(3) Establish alternative percentages if the utility system using the groundwater basin can provide guaranteed blending supplies.

4. Indirect Recharge. Groundwater supplies are augmented by irrigation return flow, drainage, and percolation from other uses, including residential septic tanks.

These indirect discharges exist, and criteria are needed to govern the future operation of water management practices that impact groundwaters. Initial criteria should be directed to alleviate known contamination problems such as the groundwater nitrate accumulations.

Surface Water Augmentation

1. Stream Flow Augmentation. A potentially significant non-potable use of wastewater is an augmentation of stream flow in arid areas, or in areas where diversions have depleted streams, or salt water has intruded undesirably into estuaries.

Since effects are non-potable (unless, as in the case of the Sacramento River, some potable uses take place near the salt/fresh zone), primary criteria for reuse would consider the environmental effects through CWA water quality criteria and stream standards.

2. Wastewater Discharge. Water quality criteria and standards are appropriate to protect all downstream fresh water uses. Supplemental criteria describing time lapse, dilution, reliability, and technology requirements for wastewater treatment should be adopted for potable reuse.

Industrial Uses

1. Water-based Processes. As water demands increase, lower priority uses can be satisfied with lower quality water. Criteria should relate to the safety of workers who are exposed either through body contact, aerosols, or accidental consumption where dual systems exist; and process or economic factors that may be affected by total mineral concentration or specific constituents.

EPA, in consultation with the states, should develop health-related criteria; but process-related criteria should be the responsibility of industry on a case-by-case basis and, in some cases, through industry-developed standards.

2. Energy Generation. The two types of criteria identified for industrial processes are needed for energy generation. The economic criteria include such factors as scaling control, fouling due to organic materials, control of nutrients, and blowdown or disposal possibilities.

EPA should develop health-related criteria and encourage the power industry to develop criteria for use of wastewater for cooling. Considerable experience exists but has not been formalized.

Irrigation

1. Agriculture. Health effects include the effects resulting from consumption of crops, indirectly through fodder crops, and the effect on workers during growing or processing. Criteria developed by the National Academy of Sciences (Water Quality Criteria--1972), by the EPA construction grants program and by some states, including comprehensive criteria by the State of California, are similar but differ with respect to numerical criteria. Such differences should be addressed in future considerations for national criteria guidance.

An increasingly important irrigation consideration is the economic effect of individual and collective constituents contained in wastewaters. There is a state and national interest in maintaining agricultural productivity. Thus, wastewater reuse may be desirable in the short term, but its possible adverse long-term effects should be recognized.

The Department of Agriculture should develop planning criteria for the economic usefulness of reclaimed wastewater for various types of crops considering soil and other sources of water and potential reversal of mineral secretions.

2. Urban Landscaping. The construction of independent systems to supply designated urban landscape irrigation needs is becoming economically attractive in many areas. This type of use is practiced successfully in the Southwest. Health-related criteria should include regulations on the proximity of spray applications to human activity, safety controls of distribution systems, and failsafe treatment facilities or alternative supplies in the event of wastewater reuse process failure.

3. Dual Systems. Dual systems which provide for a matching of water quality with needs should be encouraged. The higher

initial capital investment can be offset by the more efficient use of water in areas with limited supply. Dual system experience has been generally good. The primary purpose of dual systems is to provide a separate system for urban landscape irrigation covering a larger area than specific sites such as freeway landscaping, amusement parks, recreational lakes, and other similar uses.

CONCLUSIONS

Wastewater will be used in increasing quantities for irrigation, industrial, and energy-generation cooling purposes. It has been contended that large quantities of wastewater have not been reclaimed due to high treatment technology requirements or strict planning criteria imposed by health agencies. With the possible exception of groundwater recharge, this has not been trus--the key factor being preference for alternative sources.

Current uncertainties regarding health risks will continue, and in imperative situations, risks will be taken. When local water managers perceive a water supply need that can be met through reuse, it should be compared with all alternatives that may be attractive under the local circumstances. It should be understood that exceptions to the criteria and standards can be made particularly where concentration limits are conservative or uncertain, and the alternative supplies are not particularly desirable.

Reuse is essentially prospective, to be considered in providing new water supplies or making more efficient use of existing supplies. The approach should be broad, including the establishment of specific health standards, and calling for analysis of economic and practical considerations so that water managers can balance risks and costs within rationally defined ranges.

To provide for the beneficial reuse of wastewaters where the principal and immediate uses are non-potable in character, the following actions are needed:

1. EPA should, in cooperation with the Departments of Interior and Agriculture, adopt a water reuse policy. The policy should encourage the use of wastewaters to meet the nation's needs and emphasize their inclusion in comprehensive local, regional, state, and federal water resources planning.

2. Formalized and regular guidance should be provided to water resources planners on potential health effects of wastewater reuse.

3. Dilution and time-related criteria are needed for the planning of projects to augment groundwater and surface water supplies where non-potable uses may affect potable supplies and for potable reuse.

4. Criteria are also needed for protection of groundwater supplies (potable and non-potable) from the adverse effects of drainage and surface and subsurface waste disposal practices.

5. When criteria are established for toxic substances, including synthetic organics, the criteria should not be designed as "single number" criteria for raw waters but as ranges of concentrations to provide the basis for assessment of risk along with the evaluation of costs of alternatives.

6. In addition to constituent concentrations and dilution/time lapse guidance, reliability goals should be proposed for reuse systems serving each type of use.

7. Design, operation, and maintenance guidelines should be prepared for dual distribution systems, including standards for system location, operation, and identification to minimize accidental body contact, ingestion, or exposure to aerosols.

8. Since industrial uses are primarily controlled by quality-related economic factors, and such uses as urban landscape irrigation, stream flow augmentation, and recreational reservoirs will not provide significant reductions in the need to develop new fresh water sources, groundwater recharge and irrigation become the two most significant potential non-potable reuse applications. EPA, in cooperation with appropriate agencies, should develop a water reuse strategy similar in approach to the groundwater strategy. The first priority should be for agricultural irrigation where existing information is adequate for criteria development. The second priority should be for groundwater recharge where current studies should establish a better basis than now exists for such criteria.

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FINAL REMARKS

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PANEL: WHERE DO WE GO FROM HERE? - ROCKY ROAD AHEAD

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While the need for municipal water supply is local, all but the simplest water supply projects involve federal and state agencies: e.g., Soil Conservation Service (U.S.D.A.), Federal Water and Power Resources Service (Interior), Army Corps of Engineers (Defense), and state water resources agencies. Under existing institutional policies among federal-state-regional-local governments, the following are pointed out to be potential problem areas:[1]

1. Efficient operation of federal reservoirs as a unified system is often precluded.
2. Quantitative and qualitative analyses of groundwater, regulations of it use and its protection from degradation have been neglected by most political units.
3. The interrelationships and interdependence between the quantity and quality of groundwater and surface water is too often ignored in water allocation and water quality protection.
4. Available surface waters are sometimes committed to present demands without regard to future potable water supplies.
5. Water supply and wastewater treatment projects are separately planned, financed, and constructed by different agencies under different statutes and regulations.

Domestic and commercial withdrawals which include most drinking water, are about 29 billion gallons per day and are expected to increase to 37 billion gallons per day in year 2000.

Consumption by these uses is about 7 bgd and is projected to be 9 bgd. Obviously, domestic and commercial water needs are small compared to other uses (6.9 percent based on year 1975 total consumption)[2]. For example, agriculture is responsible for about 47 percent of freshwater withdrawals and 83 percent of consumption. As a first step in assessing the adequacy and dependability of drinking water supplies, water supply availability is compared to the U.S. Water Resources Council's present and projected use[2]. This comparison indicates that, on a nationwide basis, stream flow and interactive groundwaters represent more than twice the total withdrawals estimated for either year 1975 or 2000, and over five times the estimated consumption.

If attention is focused on domestic and commercial uses, it is seen that anticipated withdrawals in year 2000 are only about 5 percent of the once-in 20 year drought stream flow. Such a comparison, however, does not show an immenent nationwide shortage of drinking water; instead, it tends to highlight an apparent national richness in water.

The problems confronting us today in developing protocol for potable reuse are that we are reluctantly committing ourselves to the protocol development, and hoping that we will never find a situation where we will have an emergency case of pipe-to-pipe direct reuse of wastewater for potable use.

However, there are many side benefits of protocol development for potable reuse and other feasible alternatives. Perhaps, the exercise is very similar to our space program; that is, to reach the moon, we have developed much ancillary technology such as the rocket, telecommunication, and heat resistant material. We can all benefit from such ultimate application of wastewater reuse and point to the future direction of feasible alternatives.

From the practical side, our position is that groundwater recharge with reclaimed water for the planned augmentation of groundwater supplies is our goal at present. As pointed out by Mr. Culp and Dr. Roberts, and others, there are several advantages in storing water underground. After careful pretreatment of wastewater, groundwater recharge would seem to provide substantial safeguards against the penetration of chemical and microbiological pollutants from the point of recharge to the point of use. Furthermore, the greatest advantage of including groundwater recharge in potable reuse is the loss of identity in the "simulated indirect reuse" as Mr. Culp pointed out. Inclusion of a groundwater recharge scheme also facilitates a conjunctive use of surface water and groundwater which is considered to be a desirable feature of future water resources development.

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FINAL REMARKS

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REMARKS BY

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"As I visited the various workshops during this meeting I was reminded of a statement for which our new basketball coach at Dallas is reportedly famous: 'The opera isn't over until the fat lady sings.' From what I heard, it's obvious that we've written the opera, given the overture, first act, and paused for the intermission. At this point, I judge we are now well into the second act. The consensus seems to be, that while we are well along, the fat lady hasn't sung yet.

I do observe very hopeful signs of mutual education and an approaching consensus. This has been preceeded by much disagreement, some hysteria, both justified and induced. We are beginning, however, to wed the practicalities of politics, money, acceptable risk and achievable public health objectives. We all agree, I believe, and this is a point of departure for EPA, that prevention is better than cure. Practical and achievable measures to implement the pretreatment and the hazardous waste control laws deserve the full and wholehearted support of designers, managers, and builders of drinking water and wastewater treatment facilities. EPA's Office of Drinking Water must also increase its effort to coordinate in this area the efforts of its respective responsible divisions.

Solution of the unknowns, determination of acceptable risks and establishment of reasonable and achievable standards and timetables deserve a deliberate and cautious course of action. In the meantime, I must pragmatically insist that matters of great immediate concern are going unanswered while we ponder and debate the real but long-term health possibilities. There are immediate threats to public health from drinking water which are masked by the pervasive hysteria accompanying the carcinogens. Inadequate production and distribution facilities deserve immediate attention. Both groundwater and surface water sources are being depleted, allocated to low value uses, polluted and consumed. In most cases, institutional corrections are required, especially for groundwater. Many states do not control withdrawals or actual destruction of groundwater aquifers. Is groundwater a natural resource subject to allocation or a mineral right? This question must be addressed. We need to proceed and to encourage, as a first priority, improvement and modernization of plants and facilities. We need a facilities assessment to determine the extent of these needs. I once again state, without equivocation, that low pressure in a water distribution system is far more dangerous and demanding of immediate remedies than the long-term potential health effects of micro-concentrations of organic and inorganic materials.

Better and more proficient management and operation has been addressed. I am delighted to see this, because it remains a problem. Many of our small water systems, where most of our problems lie, are operated and managed by sub-professionals. The answer lies in attracting capable professionals and continuing training.

Conservation was mentioned in connection with reuse and alternate uses. There has been much discussion about conservation, reuse and alternate uses of wastewater. Alternate uses raises grave problems. Consumptive use and the attendant build-up of organic and inorganic contaminants is a major problem facing many areas of the country. We must keep in mind while we deal with more exotic problems, that salt is the great pollutant. I agree with

Dan Okun that our concern for source supplies is one of first priority. While municipalities only use 7 per cent of the water, at least 20 million people use water from sources that are subject to substantial return flows. In many such instances, build-up of total solids will present a problem eventually. The fact that electric power generation and industrial uses will recycle 865 billion gallons of water by the year 2000 means that we are going to have some problems. We want the return flow; it is a valuable commodity in many areas. But solids build-up due to consumptive uses will present significant quality problems. Studies made on the Trinity River in Texas indicate that total solids will double at the mouth of the Trinity by the end of the century from return flow recycling and consumptive use by the major metropolitan areas along this river.

So, forced evaporation must be carefully evaluated on a site selective basis as a solution to thermal pollution. The same is true of agriculture which is a major consumptive use of water and often represents a one-time use of water. We need to control water lost to the area of origin through evaporation. Worse than polluted water is no water available for reclamation. Russell Culp reported the impact of demineralization where salt is involved. Costs skyrocket to a point that the product can only qualify for the very highest value uses. So reduction of chemical build-up from recycling is of great importance as is conservation of water through reduced consumptive uses.

Where do we go from here? Well let's acknowledge indirect reuse and be positive, not negative. We must continue to build conventional drinking water plants, but provide for treatment options to be added to the process when we gain the knowledge and assurance that those options are safe and cost-effective. Our symposium has highlighted significant progress in our knowledge and awareness of potential problems. Undoubtedly, we will begin to incorporate many of these additional treatment processes, but let's be sure that the cure isn't worse than the disease.

For example, the National Academy of Science's study on evaluation of activated carbon for drinking water points out the need to take a look at the health effects of what comes off of carbon as well as that which goes on. This matter of desorption, competitive effects and adsorption equilibrium still has some knowledge gaps. The simple truth is, concentration and desorption may be worse in some instances and not useful. At least this is the feeling of those who have to design plants and those who must operate and pay for them.

It is significant, however, nearly all designs for water renovation plants have included high lime and carbon processes. Not always for removal of micro-concentrations of organics, but for taste, odor and color removal. We employ high lime and ammonia stripping and receive a bonus of bacterial and viral kill and phosphate removal. Removal of color, taste and odor are salable products. Barrier protection against slugs of toxic wastes is a reasonable precaution, and a desirable water quality objective. Perhaps we can accept granular carbon as a recommended industry process for these purposes more readily if we can avoid hysteria over micro-concentrations and cancer. Perhaps we should study the Rhine population and see if our proposed parameters can be proven to be of real health significance there. Certainly this river presents a good example of a polluted source, where significant concentrations of organic and inorganic wastes have existed for many years.

One thing is certain. We can't stop building and improving the conventional systems we have, until we prove we need additional processes. In specific instances, we probably need to move on with GAC because of taste and odor and quantity of return flow in our source; micro-concentrations and health effects aside. Even though we reject prescribed techniques by Federal regulation, that should not preclude a decision to apply innovative processes, if we think they will produce a superior product, even though not a proven health necessity. If those processes are themselves proven safe, then a superior product deserves our recommendation. As engineers, designers, builders, and operators, we must exert leadership and statesmanship as well as restraint.

Remember the zero has been re-invented. We will continue to have a moving target. Sources of supply will become more limited and of lower quality as our population increases. Our customers and our citizens must have confidence in our ability to provide safe and reliable processes. They must be sold, however, and not forced any further through fear and crisis."

FINAL REMARKS

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Remarks By

PERRY L. McCARTY

"There has been much discussion about research needs at this meeting. While my topic also is concerned with research, rather than to further discuss research needs already outlined, I would like to address my comments to whether or not such research is worthwhile. People are concerned about the high costs involved and so I would like to address the value of the information that might be obtained.

We have listened to many views about how to solve the problems concerned with water reuse. Administrators solve problems by making decisions, lawyers by passing laws, congressmen by spending money, educators by training people, researchers by developing knowledge, and many by ignoring the problem. In the case of direct water reuse, the latter method has largely been used in the past. I am happy that with this workshop EPA has taken the step to raise in significance the problems associated with direct water reuse. Over the last few years since the Boulder conference on water reuse much technical progress has been made in clarifying the issues associated with direct reuse.

I am supportive of the need to use and protect from contamination the best sources available for drinking water. On the other hand, we should be aware that either for social or economic reasons, many communities use highly contaminated waters. While the Landis Water Company in London, mentioned by Dan Okun, moved upstream on the Thames River and thus avoided cholera, we should also recognize that there were many other communities that did not choose to take that step and were thus subject to infectious disease from their drinking water. For decades after the germ theory of disease evolved, people argued whether water, in fact, was a carrier of disease. It required the technology of filtration near the turn of the century, and then disinfection, before the problem really decreased in significance. In other words, technical solutions were required to protect people from the problem. The expense of alternative water supplies was evidently considered too high by many then also.

Today we have another environmental problem equal in magnitude to the infectious disease of the past, and that is the problem of cancer. Many of the same questions are again being raised -- we do not know the sources of the problem and indeed whether or not water is involved to a significant extent. Perhaps with all the uncertainty, the prudent thing to do would be to abandon all contaminated waters and use only pristine waters. But people are unlikely to do that. In fact, even with the known carcinogens in water and even though inexpensive ways of reducing this problem have been developed, there is still strong resistance to make the relatively simple changes required. Such resistance is something we have to recognize.

It seems to me to make little difference whether someone gets sick from indirectly drinking reused water or from directly drinking reused water. We must ask the question as to why are we addressing direct and indirect reuse differently? In one session at this meeting it was indicated that we treat indirect reuse like civil law and treat direct reuse like military law. In other words, indirect reuse is innocent until proven guilty and direct reuse is guilty until proven innocent. This is an important and probably accurate distinction. Now, it is true that the need for direct reuse in this country is small. Nevertheless, the questions that are being raised here about direct reuse are the correct questions that we should be raising about all our water supplies. And it certainly is apparent now that we cannot assume that only surface waters are contaminated. It is evident that many groundwaters are highly contaminated too. It is important to raise questions about the long-term health effects of drinking any contaminated waters.

An important aspect about the direct reuse question is that we can study it without raising fears among people about their existing water supplies. If we start identifying potentially harmful chemicals in the public's current water supplies, their fears will be aroused. With reclaimed water, it is politically much easier to raise and research these questions. Thus, I believe public health questions about contaminated water supplies can be addressed easier within the context of direct reuse than with existing drinking water supplies.

There are many examples of the benefits that can arise from studies of direct reuse. For example, in current applications of activated carbon treatment to drinking water supplies some of the only full-scale plant data available resulted from studies on wastewater reuse. The development of air stripping and knowledge of its advantages in the removal of trace organics was developed from reuse research. The knowledge that we have today on movement of contaminants in groundwater to some degree was developed through studies on wastewater reuse. There are benefits to the whole water works industry that can result from studying problems with waters that are very contaminated. Thus, I believe there are good reasons why we should increase efforts in research directed towards understanding the problems associated with direct reuse for drinking water supplies.

FINAL REMARKS

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Edited by J. J. Cassidy

Edited Remarks by
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at meeting entitled,
"Protocol Development: Criteria & Standards for Potable (Water) Reuse
and Feasibility Alternatives"
July 31, 1980
Warrenton, Virginia

The word "safe" has been used numerous times today and it is a word that makes me, as a public official concerned with public health, cringe. I cringe at the expression "safe" because the question arises, who defines safety and what are the criteria by which we evaluate the presence or absence of a safe water supply? This becomes an especially difficult problem when it is applied to direct recharge and water reuse. Who is going to set the criteria for evaluating risks to a large population? Who is going to accept responsibility for weighing involuntary health risks against voluntary ones?

We in the New York State Health Department recently attempted to determine the extent to which the public was informed and interested in the problems associated with organic contamination of drinking water. We did so through a statewide series of public hearings at which we solicited community opinion on the contamination problems and putative ways of dealing with them. What we found was that, in general, people are not concerned with these problems or that they are unable to address the key issues involved; to wit, what is, in fact, a safe drinking water supply, and what is an acceptable or necessary level of risk from contamination?

Perhaps it was facile to suppose that, in a democratic society, a large segment of the populace would become involved in a decision-forming process that is going to have a direct impact on the determination of the quality of water which flows from their taps. And perhaps we were naive to think that, because dealing with the problem would require large quantities of money that had to be expropriated through the tax structure, the body politic had an obligation to bring the citizenry into the whole process. We discovered, in fact, that in areas of the State where a new water treatment facility was clearly needed, there was a far greater enthusiasm to invest public dollars in a civic auditorium, office building or a sports complex, than to invest them in water treatment. In other words, the public perception was that tax dollars were better spent for these things than for improving the quality and safety of the drinking water.

And, when the question of risk assessment was raised, the response was likely to be one of indignation that public officials would try to provoke thoughtful discussion on a subject so abhorrent as the determination of acceptable rates of excessive mortality and morbidity.

In the wake of these hearings, we found ourselves still faced with the essential questions concerning water purity standards and the impact of contamination on long-term health risks. Unfortunately, the epidemiologic studies available to us do not provide definitive answers concerning the health impact of micro-contaminants in drinking water. And I have to say that, given the current state of the art, epidemiology is a very weak tool in terms of determining the long-range impact of trace levels of water contamination and comparing it to other health risks commonly encountered in our environment.

Nor have we identified our target population. Are we going to protect all members of society? Or are we simply seeking to protect the sick and infirm, or those who suffer from immunologic abnormalities that make them extremely susceptible to low concentrations of microorganic compounds? Are we going to extend the same level of protection to every community, regardless of size and nature of water supply?

I think that we have to address the question, not in terms of what is an appropriate level of risk, but rather, what is the necessary level of risk. And in determining the necessary level of risk, there are obviously a large number of factors involved, some over which we have no control. They relate to the economy, the tax base, and to a variety of social and political issues. One of the major concerns we have as a health agency is that the costs of monitoring and protecting the public water supplies often must come from already straitened resources for public health initiatives. Which raises the whole question of society's responsibility to protect its sources of water from contamination, so that drinking water will not only be safe but economical as well. In some places in New York State, we already know that the quality of water used in recharging the aquifer is higher than the water found in the aquifer itself.

The costly legacy of these areas of the State with respect to groundwater treatment is one which residents and future residents of these areas are going to have to bear for a long time to come.

We face another major challenge. And that is with respect to the kinds of analyses which have to be carried out to determine if drinking water is of acceptable quality. The complex nature of these tests, the range of analyses required, and who should perform them--all of these issues have been discussed in the news media. We have found what I'm sure many of you have found: the number of institutions, laboratories, and universities capable of carrying out sophisticated laboratory analyses in reproducible fashion is relatively limited. And very often, more damage is done by the release of incorrect results than if no results had been reported in the first place. We spend almost as much time correcting analytic misinformation as we do in providing correct information to those communities and individuals who are seeking and have a right to that information.

In dealing with the problem of chemical contamination of our water supplies and the setting of standards, I believe we must separate political considerations from scientific ones. We, as scientists and guardians of the public health, have to make objective judgments with respect to what we believe are realistically acceptable levels of contamination in drinking water. These may not necessarily be the same for all areas and supplies.

However, the scientific evaluation of techniques for the removal of contaminants must be separated from the political process. The political process will ultimately bring all these factors into balance. Therefore, I think it is important that public health agencies steer clear of the political arena and resist the temptation to say what is safe and not safe. I think we have a clear mandate to say what the likelihood of risk is with respect to individual chemicals and overall levels of contamination, and leave to the political process the value judgments.

We can make general statements, but I think we should eschew determination of what is, or is not, safe. Because, what is safe for one individual may not be safe for another. What we can and should do is project on the basis of available scientific information the likely health impact of long-term exposure to various kinds and concentrations of water contaminants. Then, the people, through their elected representatives, should decide what needs to be done.

With respect to water recharge and the problems associated with it, I can only say that in New York our experience has been that recharging seems particularly promising in coping with contamination problems associated with sole-source aquifers. Most of these problems stem from agricultural use of lands and from intemperate and unwise industrial discharge practices. We are very hopeful that the newly emerging criteria and technology for water recharge will provide the answer to many of these problems. We believe that the responsibility for developing water recharge standards rests with the federal government, and that this responsibility should not be fragmented among the states.

Thank you for offering me this opportunity to express my views on this subject.

FINAL REMARKS

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"Jerry Gilbert said something that comes home to me and that is that reuse must be considered in the total resource system. That is something that we all perhaps agreed to and would agree to, but somehow we never quite reached that point. The entire environment has got to be considered when we decide or make decisions about whether or not we reuse water. Whether it's for direct reuse or indirect reuse, potable or nonpotable reasons. I've been involved in water reuse issues since 1963 when I worked for the Los Angeles County Sanitation District. As you know, that group developed a reuse strategy and I believe as yet they haven't implemented it. But what we failed to do, I think, is to develop, and I hate to use catch words, but develop management system strategy. A process, protocols, if you will, when protocols are needed and standards will help us define what the residual risks are after certain treatments. A process which manages environmental quality would set goals that are larger than just getting water from point A to point B or to Group C or whatever. And we must do it in such a way that we minimize the risk of misallocating the public resources and that is an important goal. In other words, what we all come to believe, I think, certainly the economists in the crowd can tell us, is that prices should reflect both the private costs as well as the social costs. And we run the risk of skewing that and preventing that from occurring, when we subsidize one system over another. When government subsidies favor one source of water supply over another, whether it be recycling or alternatives to that, problems arise.

I would like to mention two examples which I think point out, at least to me, what I consider to be this problem. And that is the focusing on management strategies of looking at the entire environment rather than narrow the questions as to what is safe and what is not safe, and I think what Dr. Axelrod said I would fully agree to. In Long Island, when I was with the Environmental Defense Fund, we struggled against federal and local agencies and managers who did not want to recycle. And in this case it was indirect groundwater recharge. As most of you know, Long Island is wholly, at least in Nassau County and Suffolk County, dependent on groundwater resources. They really have no surface water resources. And the alternatives are rather grandiose. Importing water from upstate New York would have many hurdles before utilization, I am sure. The situation there was one of cutting off that alternative of recycling whether it be direct or indirect. Local discussion never got that far. I maintain that in doing that, that in effect, at least from the point of view of public health, that those advocating that solution, a solution which discounts recycling because of the 'unknown' health effects, run the risk of placing an infinite value on a human life, This misallocates the public's resources. I don't think that anybody has really studied it extensively enough to know what the alternatives are in providing the public , industry, and commercial enterprises with water to meet future growth needs. But clearly sewering that population which is being done in many areas, for example the Southwest Sewer District, and transporting that waste to the ocean, treating it in very classical way of secondary treatment will reduce groundwater levels. It will reduce the flow of water into the Great South Bay and increase the salinity of the Bay and may jeopardize the shellfish industry which is a very large industry ($20 million a year as I recall). All this in the name of the unknown health risks associated with groundwater recharge or injection or for that matter direct recycle. What was needed there, I believe, is what is needed in almost all of these instances, a very direct consideration of the recycling alternative. There are unknowns associated with any alternative for supplying water and for that matter any public service. We're not unique in having the residual of unknown health risks associated with direct or indirect recycle for domestic consumption. We should not treat it as such. To do so, and I again repeat, runs the risk of placing an infinite value on the human life. Now, we may not be able to tell the public. But I believe we are getting closer and closer to being able to at least put bounds on the risks that remains on the residual organics in the water. We may not be able to tell them precisely what that risk is. But we can certainly contrast the range of risks as we now know it with the cost of the alternatives. Jeopardizing of the shellfish industry of Great South Bay is an example as is the discharge of chlorinated material into the near shore waters and a possible incorporation or concentration of these materials in fish and shellfish which also introduces unknown health risks. All of these can be placed in some sort of context and some sort of process which I believe would lead us to more rational decisions and probably in many cases would result in greater use of recycling for domestic consumption, particularly groundwater recycling.

Another example is the District of Columbia, which has struggled for years to supply water for a very rapidly growing population. Of course the arguments there have been more dams upstream. Of course these are subsidized. The real cost to the businesses and to the public that lives in Washington will not be transferred to them, but will be spread out over the entire population as in the form of federal subsidies for dam construction. But dams have been temporarily halted as a solution and we are now looking at indirect recycle through the estuary. Is that a viable alternative? I would maintain it is. Do I think that that will be ultimately the solution let's say in the next 20 years? No, I don't. Because I believe, and I don't know, but I believe, that once we have the information on the health effects, the benefits of allocating money that we might spend for treatment techniques necessary to clean up the estuary might be used for treatment of existing water treatment plants, development of offstream storage during flood flows, interconnections, pricing, and conservation - I don't think that in the next twenty years we will go to the estuary as a source of indirect recycling. But to discount it as having too many unknowns, I think, is a disservice to the public. I don't think there are any more unknowns there than the environmental consequences associated with developing new sources of water and a host of other alternatives for supplying future demands. It's been said that we can evaluate the water in the estuary by comparing it with New Orleans. And many of us said that when we do, we'll probably see that the water quality that we could develop from advanced waste treatment processes using estuary water will give us a water quality which is better than New Orleans drinking water but perhaps and maybe even more importantly far better than the water that the residents of the District of Columbia are now drinking. Well that doesn't argue in favor of using the estuary because we can obviously improve the quality of the water that the residents of the District of Columbia are now using. And one would have to factor that into the equation. What is the marginal benefit of investing some of the public's resources in better treatment and better protection of the existing sources? So these are two examples. Who could argue against research, particularly in this area? These are the very same questions toxicologists raise about testing mixtures. And the chemists' problem of not knowing what is representative in terms of a sample that water in the Delaware is coming out of a sewage treatment plant and it varies minute by minute, day by day, week by week, and do we composite it? Surely that's not totally acceptable. It's like compositing samples to do dissolved oxygen levels. Fish don't respond to monthly or yearly dissolved oxygen. A week's worth of 0 dissolved oxygen and the fish are gone. So research, I think, will be very helpful in narrowing the gap of the unknown. That is, what we can tell the public is the true risk or what the residual unknowns are. That is, how much risk might there be, but we cannot answer the question definitively because we don't have the information. But obviously this research is crucial and parallels the information that we need for better protection of existing supplies. So, in conclusion, what I would say that what we need is a process development very akin to the National Environmental Policy Act goal of requiring federal agencies to do environmental impact statements. And the reason for that is to force agencies to develop all of the alternatives and to lay them out for decision-makers and the public very early on in this decision-making process. We should not discount the alternatives because we don't know or have little information on one facet of it or another. If indeed, we develop that sort of process, that is a way of accounting for the health risk, the real cost of supplying water for the public by reuse and we develop a way of factoring that into the decision-making process in a way that develops the proper information for all the alternatives so that we know what direction to go, that over the next 20 years we will be recharging groundwater a great deal more than we are now. And we will be supplying reused water for nonpotable uses in even much greater amounts. That is, obviously to me at least, the largest untapped resource or let's say potential for reusing water. And last, I doubt very seriously if there will be very many, if any, direct reuse situations.

CONCLUDING REMARKS

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Concluding Remarks
C.C. Johnson, Jr.

"I would say we've had an energetic, enthusiastic and productive two days. It's something like one old gentleman told his son, 'Dad, what is wisdom?' 'Oh, son, you get wisdom through experience. We've certainly had a number of experiences.' The son said, 'But how do you get experiences?' The old man said, 'By exercising bad wisdom.' I think a little of this goes on in all our lives and all of our pursuits.

This particular conference or symposium is one that the Drinking Water Council has long hoped would occur. When I finish, you will probably see that we've perhaps had a hidden agenda from our viewpoint. But it all comes out the same in the end. So let's start back on Tuesday morning and briefly look at the charge or the purpose for the symposium so we can get things in the proper perspective. I will read a sentence that prevails here.

> "'The purpose of this symposium is not to develop specific criteria and standards but to provide guidance with respect to approaches, problems, solutions and needed research for investigation for establishing a pathway to protocol development for potable reuse criteria and standards and for consideration of non-potable options.'"

Joe Cotruvo, when he sent you off to your deliberations, gave you two basic charges. First, 'please come back with recommended basic principles that can be used in the decision-making process.' He didn't ask you to make any decisions - just tell EPA how it ought to go about doing them. Secondly, please recommend specific experiments that can be constructed so that their interpretation will help to answer the questions that remain.'

Also on Tuesday we had six speakers that helped to set background and pose some of the issues. Lloyd Fowler said that there are two basic issues involved: one, that potable reuse should be the result of a need. Either there is water in short supply or there is a reason to extend a good quality water for other purposes. The second need was, that whatever potable reuse considerations are given, the quality is important and public health must be protected. He believed the existing water supply standards were adequate, but that perhaps direct reuse poses additional questions. Dan Okun sounded a note of caution and said that we need to review the use of the sanitary survey so we know what is happening to the source and why. It was Dan's view that we should save the highest and cleanest sources for the highest priority use and that is drinking water. He reminds us that 95 percent of the public water systems serve less than 10,000 population units. He said that the Drinking Water Act does not address quality of the source and this should be considered. And he said that the preventive health benefits, that is the need to act before catastrophe arises, should be paramount in our thinking. Ken Miller had a slightly different viewpoint. He said that the time for criteria development of standards for potable reuse is now. But, he said that reuse should occur only after all other options or alternatives are exhausted. In Ken's viewpoint the concept of an uncontaminated source should not control a potable reuse consideration but that technology should control. Ken was concerned about process reliability, but, also, the flexibility in the selection of the treatment processes. And finally, he said that standards for health must relate to economics, process technology, public acceptance, health effects, and most of all, the real world.

Dr. Brinkmann related some of the experiences that they had with the many plants set up for non-potable reuse in Europe and also some that are set up for limited direct reuse. One popular mode that we have become familiar with and have exhibited some interest in is river bank infiltration. He also noted that they have worked in parameters for reuse that are similar to those in California for standards for infiltration and injection into the ground water source.

Duane Baumann brought a perspective on public acceptance. He reported on an attitude survey which noted that social acceptance was not an obstacle - given a educated public. He also said that major obstacles are probably in the minds of public health officials and engineers. Bob Madancy, the spokesman for the non-potable and other alternatives sector, raised the $64,000 question. One that most people tried to stay away from and ultimately found that they could not. He wanted to know what is potable reuse? What is direct? What is indirect? He cited as an example the stretch of the Ohio River between Pittsburg and Cincinnati. Is Cincinnati's water direct or indirect reuse if it's 2,000 feet away, 200 feet away or 2 feet away from a discharge? I believe you need to think about that. He also pointed out that figures show that potable reuse is only, or probably less than, 1 percent of all the recent reuse projections to the year 2000. And he noted the simplicity of preparing for non-potable reuse process training as compared to potable reuse process training. He did recognize that public health is the most important aspect associated with potable reuse.

At this point, we got our final charge for the workshop deliberations. They were essentially in four areas -- consider the source, consider the quality, consider treatment, and consider monitoring needs. My summary, from hereon, will address comments on these four elements as well as other matters that evolved out of my observations on the workshop, its deliberations, the review of the issue papers, summary statements and the recommendations that you have heard today.

I will note that I did sit in, albeit in short order, on each of the workshops which meant that I got a disconnected view from the discussions that were carried on. Thus, these observations that I bring now, are somewhat permeated with my own philosophy, perhaps as I thought and hoped that things might turn out. Nevertheless, I think they are worth your consideration.

First of all, what sort of a listening posture did I take? I sat down and I listed perhaps 20 or 25 questions that I would like to get answers to out of this kind of symposium. I'll share with you only eight that I think are significant.

Is it possible to establish criteria and standards for potable water reuse which will protect the public's health? Drinking water standards are to be applied to source waters from a protective source. What does this mean in consideration of potable reuse? Will be public knowingly accept direct reuse? Does the available scientific and technical data allow the establishment and implementation of acceptable water quality standards? What is the most likely or prevalent nature of water reuse and what is its significance or impact upon public water supplies? Does our knowledge of hydrogeology, soil characteristics and the interaction of wastewater products allow us to predict the fate of contaminants following ground water recharge? With respect to water quality in the absence of certainty, what risks to the public's health are we willing to take? What are the gaps in our knowledge that can be and should be fielded by research as we consider the subject of potable water reuse?

Let's discuss these for a brief moment. The first thing that I noticed in most of the workshops was a common dilemma, a common concern about the definitions, that we should use as we discuss this subject. I'll only point to one. I think we have to bite the bullet, we have to be concerned about it. And that is, what is potable reuse? What is direct reuse? What is indirect reuse? If we don't try to satisfy the confusion around this question, I believe that we are in for considerable semantic problems and difficulties. I would suggest a definition that skirts the above words and recognizes the reality with which we have to face and deal with decision. It has begun to creep into the terminologies of several of the discussants or the reporters here today. I heard Bob Neal talk about planned and unplanned reuse. I heard one of the other reporters this morning talk about controlled and uncontrolled reuse and I would suggest that the definition of potable reuse is the 'planned and unplanned, controlled and uncontrolled use of wastewater for domestic purposes.' And, similarly, non-potable reuse is characterized when wastewater is used for agricultural, industrial and other purposes. In case there are those of you that don't fully understand or agree or appreciate what I am trying to say, let's use some examples. Planned and controlled reuse includes, and these are actual instances, practices that exist in Israel, South Africa, Netherlands, Germany, etc. We don't have to go to Europe to get examples. It is similarly done in California and Long Island in terms of ground water recharge and in other places. It's done in terms of a raw water supply source in Virginia and I'd like to take a minute just to describe this. With the approval of the protocol that was developed by EPA and the State of Virginia, the Upper Occoquan Sewage Authority was allowed to develop an AWT plant that discharges its effluent into the drinking water reservoir which the county of Fairfax takes its raw water supply and produces water for consumption by the public in that service area. There is no better example of a direct reuse situation than that. They did it on the basis of the best knowledge that they had, the best technology that they could devise, the best reliability that they could design to. It's there and it is working. It's going to be the kind of demonstration from which wisdom is gained. We will know later on whether it was a good or bad experience.

In unplanned reuse, there are a number of examples. Every community water treatment plant that exists below the discharge of every wastewater treatment plant is in a mode of unplanned reuse. The only difference is the distance that separates one pipe from the other. This is recognized in terms of Dallas, Texas, having to contend with the discharge from Denton, Texas, and a community directly below the city of Denver, Colorado, taking the discharge from the Denver Wastewater Treatment Plant. I should point out that there are planned situations, not for ground water reuse, but planned in terms of effluent that is discharged to the ground in a relatively safe manner and that is Muskegon, Michigan. There is one situation that I should point out in which direct reuse was literally planned for in Chanute, Kansas, in the 1950's. Because of the drought, there was a critical need for water. So, the point I am trying to make is, indirect potable reuse is a reality. There's nothing new about it. Maybe our concern is new, but the situation is there, and that's the reason that I think this was such a valuable conference. We are now beginning to deal with the true terminology and that's polluted water supply sources. What do they mean in terms of our ability to produce an acceptable water supply?

Once the workshops began to adjust to dealing with source waters from polluted sources, regardless of the unidentifiable measure of direct or indirect reuse, they were intellectually free to address the problems associated with producing or maintaining potable water that is protective of the public's health. Practically all the groups believe that their deliberations were applicable and probably should be applied to all polluted waters regardless to the source. I think that's an important kind of a conclusion in this kind of a workshop.

It is commonly recognized, that the degree of pollution and characteristics of the waste involved in potable water, impacts on microbiological, chemical, toxicological aspects of water quality, in new and different ways when compared to the past practices associated with water treatment and quality assurance. Even so, there was common ground in the approaches recommended for dealing with these aspects. Practically all the groups were of the opinion, that a single set of water quality standards should apply at the tap, and that is the most definitive word, regardless of the source of the raw water to be treated for drinking. All groups agreed, or almost all groups agreed, that raw water from highly polluted sources require additional knowledge as to their origin and additional information and data with respect to their characteristics, in order to provide the necessary reliability in the treatment processes and the assurances of the quality of the water that is produced. With the exception of one work group, all the groups recognized deficiencies in the state-of-the-art required to achieve the desired objectives. These deficiencies were not insurmountable and can be remedied by additional and specified research. I am somewhat discouraged by the timetable that seems to be associated with obtaining solutions to some of the problems that surfaced. However, the engineering group is of the opinion, that technology does not appear to be a limiting factor in the implementation of potable reuse. I guess we have to recognize, we engineers are kind of an egotistical bunch sometimes.

Perhaps the most important and as yet unanswered question is associated with health effects which may be attributed to the treated waters. Toxicologists suggest that new parameters are needed to deal with newly recognized concerns for organics in drinking water. These parameters may take the form of biological end points. We're not used to working with those, we'll have to see what that means. Working with the chemists, the toxicologists believe that animal studies can be designed that will enable a measure of predictability and thus establishment of standards or protocols that can guide the design and the operation of water treatment plants.

You notice I have been using the term water treatment plants. Well one of the definitions that seems to create a problem, as we look at this whole problem of potable reuse, is the use of the term water reclamation plant. I am not quite sure where that term fits into my thinking, when we consider all of the water plants that now exist under planned or unplanned situations of potable reuse that are not called reclamation plants.

Microbiologists agree that potable reuse raises new questions with respect to the presence, generation, and reduction of pathogens and toxins during water treatment of highly polluted waters. This may require new indicator organisms and different disinfectants than those that have been used and relied upon for the past 100 years. Even so, the required answers can probably be supplied by appropriate research.

Serious questions exist, and I probably should say in my mind, about the ability to predict the transport and transformation of metals, organics and biologicals in ground waters. Under these circumstances, either the doctrine of no significant deterioration or the concept of dedicated use should be applied to ground water recharge for potable reuse and reuse for non-potable purposes.

The non-potable reuse group believes that the problems of potable reuse are monumental. The volume of water involved is said to be inconsequential and the ultimate acceptance of direct potable reuse is improbable. They believe that emphasis should be placed on more readily achievable solutions of problems associated with non-potable reuse. On any concept of controlled and uncontrolled, planned and unplanned reuse of wastewater, I believe that this becomes a local option. It should probably be decided on a needs basis while maintaining consideration of protection of the public's health as a top priority. It must be emphasized that few non-potable uses exist that do not impact upon the quality of water supply that now or may in the future be required for potable uses.

So where are we? In my opinion, the practice of potable reuse has been with us for a long time. We need only to improve the product and keep pace with our knowledge and concern for health effects. I believe that this affects every community water supply that currently extracts water from an industrial or vulnerable stream or grossly contaminated aquifer. We can't stop the world or close down these water treatment processes while we obtain answers to the scientific and technical gaps that exist. We must get on with the business at hand of producing the best water from the sources we must use. We don't have many choices in some places. We must do this in the presence of the best available knowledge we have as inadequate as this may be. If our concern for water reuse is genuine, then it is strongly recommended that the deliberations, considerations, and recommendations of this symposium be related as applicable to all aspects of potable water supply production. Recognition of this concern involves every program within the purview and responsibility of the EPA, and impacts on the quality of raw water supplies sources, and the development and revision of national drinking water standards."

SUPPLEMENTARY OPINION
ON THE TOXICOLOGY-HEALTH EFFECTS PROTOCOL

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SUPPLEMENTARY OPINION
on the TOXICOLOGY-HEALTH EFFECTS PROTOCOL

by: Prof. G. Shelef*

INTRODUCTION

The test procedures recommended by the work group constitute a major effort which might involve some five years and five million dollars for study of one source of water. It will also involve toxicologists, histologists and other expert manpower which are in short supply and heavy demand.

The above expenditure estimate might prove too optimistic considering the need to develop large-scale technology to concentrate the organic residual using a considerable flow of water due to unforeseen problems associated with such complex endeavors.

Assigning the major effort to three to five experimental or demonstration-type direct potable reuse schemes will not in my opinion, be the most effective way to use the limited monetary, manpower and time resources available. This is particularly true when many communities are being served today by surface water that can be regarded as indirect potable reuse. Moreover, requiring such costly and time consuming procedures on a specific, relatively small direct potable reuse scheme, will put an excessive burden on the initiating community which is in a stage of conceiving the reuse scheme.

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RECOMMENDATIONS

1. Apply the recommended toxicological procedure with a specific objective to arrive at water quality criteria which will serve as design criteria for general surface water supplies for existing indirect potable reuse schemes (in this order).

2. Apply this toxicological study to an intermediate-size community using a surface water supply for which indirect reuse is an intrinsic feature of it (such as Louisville, KY). Conduct a comparative study in a community served by a "virgin" surface water supply (without the indirect reuse element).

3. Follow the toxicological-health effect study with the most vigorous epidemiological investigation related to incidence of cancer (bladder, stomach, liver, etc.).

4. At the conclusion of the study come up with new drinking water criteria specifying two levels of concentrations.

Acceptable (Level A) and Recommended (Level B) specifying the following:

(a) Concentration of specific compounds identifiable in drinking water which are known or suspected to be carcinogenic, teratogenic, mutagenic, risky. Compounds such as (and not necessarily inclusive) chloroform, dichlorobromomethane, benzopyrene, nitrosamines, etc.

(b) Concentration of "bulk groups" of substances which are of concern (suspected of carrying health significance) such as (in an order of descending specificity) total halomethane, halogenated hydrocarbons, halo-organics, total dissolved organic carbon (TDOC), total organic carbon (TOC), chemical oxygen demand (COD) or any other group of suspected compounds.

With the existence of such drinking water standards, any direct potable reuse scheme should comply at least to the Recommended Level (Level B) or will have to comply with even a better quality (let's say by a factor of two, three or five) of what is specified in Level B.

Additional shortened toxicological tests such as mutagenesis should serve for monitoring the plant's effluent.

In summary, direct potable reuse water should not have a special criteria but should comply with vigorous drinking water standards.

Analysis of Water and Wastewater for Specific Organic Pollutants

by

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Analysis of Water and Wastewater for Specific Organic Pollutants

J. J. Lichtenberg, J. E. Longbottom and T. A. Bellar

INTRODUCTION

This paper reports on the analytical methods developed for the specific organic pollutants listed in the 1976 Consent Decree between the EPA Administrator and several environmental groups (1). It also reviews the status of gas chromatographic-mass spectrometric (GC-MS) methods for quantitative determination of these pollutants as well as methods for the analysis of drinking waters as required by the Safe Drinking Water Act (2).

A series of 13 test procedures for 114 specific organic priority pollutants have been developed and have been proposed for use in the National Pollution Discharge Elimination System permits program, (NPDES), for State certifications, and for compliance monitoring under the Clean Water Act (3). These procedures employ conventional gas chromatographic and liquid chromatographic techniques for quantitative measurement of specific organic compounds in effluents. In addition to the relatively low cost gas chromatographic procedures employing conventional detectors, higher cost GC-MS procedures are also provided for routine monitoring of pollutants. High pressure liquid chromatography (HPLC) which has developed significantly in the last few years, is proposed for certain parameters where state-of-the-art packed column gas chromatography has been unable to achieve adequate separation for quantitative measurement. Each method has been evaluated for applicability to a variety of industrial and municipal effluents, and interlaboratory studies are underway on each of the methods to develop a formal definition of accuracy and precision and to define the limit of detection in the effluents.

A summary of ongoing and proposed future methods development research is presented.

INITIAL PROTOCOL

The initial analytical Protocol (3) provided a gas chromatography-mass spectrometry (GC-MS) method for the determination of the 114 organic compounds. It was applied to two major classes of compounds, purgeable volatiles and solvent extractable semi-volatiles amenable to gas chromatography (GC). These broad classifications were further divided into halogenated and non-halogenated purgeables, pesticides, base-neutrals, and acids as listed in Table I.

This protocol as written and used in the initial phases of the EPA Effluent Guidelines Division's program to survey 22 industrial categories was intended as a qualitative screening tool. Estimates of the pollutant concentrations found were to be reported, however.

PRIORITY POLLUTANT METHODS

The objective of the subsequent methods development was to provide a series of methods that could reliably quantify the results of the analysis of relevant wastewaters, that is, waters where known specific compounds are expected to be present. Due to the relatively high cost of GC-MS analysis and its general lack of availability in smaller laboratories, efforts were directed toward the more conventional gas chromatographic methods.

The list of 114 organic compounds was divided into 12 categories (Table II) primarily along organic functional group lines, although categories 4, 11, and 12 deviate somewhat from this scheme. The methods fall into two major classifications: analysis by gas chromatography and high pressure liquid chromatography (HPLC). With the exception of the method for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD), all of the gas chromatographic methods employ conventional low cost detectors. The method for TCDD requires the use of capillary column gas chromatography/mass spectrometry. Three of the methods use purge and trap-gas chromatography; modifications of the technique were reported by Bellar and Lichtenberg (5) in 1974. Two methods require HPLC and seven use various conventional, more or less selective, GC detectors. One of the methods, that for phenols, also includes a derivatization step. Tables III and IV present summaries of the methods with the assigned EPA method number.

It is not the purpose of this report to give complete details for application of the 13 test methods. Rather, it is to give a summary of each, indicating their scope.

A brief description of each of the 13 test methods is presented below.

METHODS FOR VOLATILE ORGANIC PRIORITY POLLUTANTS

Purge and Trap - The three purge and trap methods are used to determine 29 halocarbons, 7 aromatics (including 4 of the halocarbons) and acrolein and acrylonitrile. The three methods are distinctly different in the sorbent trap materials used and in the gas chromatographic columns and analytical conditions employed. In addition, the acrolein/acrylonitrile method uses an elevated purge temperature of 85°C while the other two use an ambient temperature. Table III summarizes the analytical conditions for this group of methods.

The difference in the trap sorbent materials is due to the variable capacity of the sorbents to retain the compounds of interest. Our studies showed that the purge and trap method as orginally published was not capable of trapping the very volatile priority pollutant compounds such as vinyl chloride and dichlorodifluoromethane. It was experimentally determined that activated carbon and silica gel were required to successfully trap these halogenated compounds. The trap composition and dimensions are as follows beginning with the inlet end: 1 cm of 3% OV-1 on Chomosorb-W, 7.7 cm of Tenax-GC, 7.7 cm of silica gel, and 7.7 cm of activated charcoal. A trap containing 1 cm of the 3% OV-1 material and 23 cm of Tenax-GC was found to work well for the aromatic compounds.

The high water solubility of acrolein and acrylonitrile required an elevated purge temperature (85^{O}C) to produce acceptable recoveries. The trap is composed of 24 cm of the porous polymer Poropak N.

Other important parameters in providing successful gas chromatography are the GC column packing, the temperature conditions, and the selection of a detector as specific to the analyte as possible. Maximum resolution of the halocarbons is achieved with an 8 ft x 0.1 inch ID column of Carbopack-B coated with 1% SP-1000. The initial temperature of 45^{O}C is held for 3 minutes and then programmed at 8^{O}C/minute to 220^{O}C. An organohalogen detector (OHD) is used. The aromatics are best resolved with a 6 ft x 0.085 inch ID column of Supelcoport coated with 5% SP-1200 plus 1.75% Bentone-34. They are measured with a photoionization detector. The temperature conditions are as follows: 50^{O}C for 2 minutes followed by 6^{O}/minute to 90^{O}C. A 6 ft x 1/8 in OD Chromosorb 101 column with temperature conditions of 100^{O}C for 5 minutes and 10^{O}C/minute to 140^{O}C was found to be best for acrolein and acrylonitrile. This method employs a flame ionization detector (FID).

METHODS FOR SEMI-VOLATILE ORGANIC PRIORITY POLLUTANTS

Table IV summarizes the methods for the semi-volatile organic compounds. A brief description of these methods follows.

Phenols - Two approaches are given for determination of phenols and, although we believe these to be state-of-the-art methods, some problems remain to be solved. The sample is extracted under basic conditions to remove potential interferences. The water phase is then acidified and extracted three times with methylene chloride. The extract is concentrated and analyzed by FID gas chromatography using a 6 ft long x 2mm ID column packed with Supelcoport 80/100 mesh coated with 1% SP-1240 DA. The column temperature is programmed from $80^{o}C$ to $150^{o}C$ at $8^{o}C/min$. The resolution provided by this column is not adequate to separate all of the phenols and if all 11 are present, the second approach, derivatization and EC-GC, must be used. After conversion to their pentafluorobenzylbromide derivatives and silica gel column chromatographic cleanup, the phenols are analyzed on a 1.8 m x 2.0 mm ID glass column containing Chromosorb W-AW-DMCS coated with 5% OV-17 at $200^{o}C$. Neither method is 100% successful for resolving all of the phenols. The nitrophenols are a particular problem in this regard.

Benzidines - The method chosen for the determination of benzidine and 3,3'-dichlorobenzidine uses HPLC. Lichrosorb RP-2 (5 micron) is used as the analytical column with acetonitrile and an acetate buffer as the mobile phase. A relatively selective electrochemical detector is used to detect and measure the benzidines. The instability of 1,2-diphenylhydrazine, which decomposes to azobenzene, caused it to be eliminated from consideration.

Phthalate Esters - These compounds are extracted with methylene chloride, concentrated, and the solvent exchanged to hexane for Florisil or alumina column cleanup and EC-GC determination using a mixed phase column of 1.5% SP-2250 and 1.95% SP-2401. This method is essentially the same as that for organochlorine pesticides.

Nitrosamines - The nitrosamines are extracted with methylene chloride, treated with HCl, concentrated, and solvent exchanged to methyl alcohol for direct nitrogen-phosphorus or thermal energy analyzer detection. Provision is made for Florisil or alumina column cleanup prior to GC analysis. The GC column liquid phase is 10% carbowax 20 M plus 2%, KOH. N-nitrosodiphenylamine thermally degrades to diphenylamine in the GC and is measured as diphenylamine after prior removal of any diphenylamine occurring, as such, in the extract. Florisil or alumina column cleanup is used for this purpose.

Pesticides and PCBs - The methods for organochlorine pesticides and PCBs are much the same as existing 304(h) methods, the major difference being in the extracting solvent. Methylene chloride is used instead of the mixed solvent (15%) methylene chloride in hexane. The GC columns, conditions and detector are essentially the same.

Nitroaromatics and Isophorone - The GC column used for determination of these compounds is essentially the same as that used for the pesticides and PCBs. Nitrobenzene and isophorone are determined at 85°C using a FID. 2,6-Dinitrotoluene and 2,4-dinitrotoluene are determined at 145°C using an EC detector.

Polynuclear Aromatic Hydrocarbons (PAHs) The PAHs are analyzed by HPLC using a reverse phase HC-ODS Sil-X column with UV and fluoresence detectors in series. The option to use FID-GC is given. The column is 6 ft x 2 mm ID containing Chromosorb W-AW-DCMS coated with 3% OV-17. It is operated isothermally at 100°C for 4 minutes and then programmed at 8°C/minute to 280°C.

Haloethers - Bis (chloromethyl) ether is known to have very short half-life in water (38 seconds). Therefore, it was eliminated from consideration in our method studies. Some other haloethers are very volatile and care must be taken not to lose them during the concentration step. The haloethers are determined by OHD-GC using a 1.8 m x 2 mm ID glass column containing Supelcoport coated with 3% SP-1000. The temperature is held at 60°C for 2 minutes and then programmed at 8°C/minute to 230°C.

Chlorinated Hydrocarbons - These include chlorinated compounds other than those classified as pesticides, PCBs, or purgeables. One of these compounds, hexachlorocyclopentadiene has been found to be unstable in the extracting solvent, methylene chloride. Thus, recoveries for this compound are variable and low . The chlorinated hydrocarbon compounds are determined by EC-GC using a 1.8 m x 2 mm ID glass column containing Gas Chrom-Q coated with 1.5% OV-1 plus 1.5% OV-225. The oven temperature for six of the earlier eluting compounds is 75°C. For the three later eluting compounds it is 160°C.

TCDD - 2,3,7,8 Tetrachlorodibenzo-p-dioxin (TCDD) is a very hazardous compound. Special handling facilities are required when working with the standard material or samples containing TCDD. We have included with this method a section on Safe Handling Practice for TCDD which has been issued by the Dow Chemical Company (6). The sample is extracted with methylene chloride solvent exchanged to hexane and cleaned up by washing the extract with sodium hydroxide followed by sulfuric acid and water. The extract is concentrated and further cleaned using either of the optional column chromatographic procedures - silica gel or alumina. These may be used independently or in series as needed.

Determination of TCDD is by capillary column GC-Selective Ion Monitoring Mass Spectrometry. The capillary column is glass 30 m long x 0.25 mm ID coated with Silar 10 C or fused silica 60m x 0.25 mm I.D. coated with SP-2330. The capillary column GC-MS gives a unique separation of 2,3,7,8-TCDD from the other 21 tetrachlorodibenzodioxin isomers.

These methods, were published in the Federal Register (3) and were available for public review and comment for 150 days. EPA is now considering all of the public comments and editing and modifying the methods as appropriate. The methods will be proposed for final rule-making in the NPDES program when this task is completed. These methods will supplement those approved (1973) for NPDES Programs. Table V lists the initial series of eight methods. Six are for Pesticides and Herbicides, while the other two methods are for PCBs and organochlorine solvents. A colorimetric method (Chloramine-T) for benzidine and its salts and methods for pentachlorophenol were added or referenced at a later time.

Additional methods that have been proposed or are being considered for proposal as 304(h) methods include the GC-MS methods for Purgeables (Method 624) and for Semi-Volatiles (Method 625) (3) and a direct aqueous injection method for acrolein and acrylonitrile. See Table VI.

INTERLABORATORY STUDIES

A brief description of the interlaboratory studies that have been or are now being conducted on Methods 601 through 613 and by GC/MS methods 624 and 625 by the Quality Assurance Branch of EMSL-Cincinnati is as follows: for each method, a minimum of twenty laboratories have been subcontracted through a prime contractor to conduct the studies. Some additional laboratories, mostly from EPA, are also participating. Six sample types are being studied in each case: distilled water, drinking water, ambient surface water and three relevant industrial waste effluents. The participating laboratories will furnish the first three types from local sources. The prime contractor will furnish the effluent samples. Each sample type will be spiked at three concentration levels using Youden pairs at each level. The individual spike of each Youden pair varies from at least 5% to not more than 20% from the selected spiking level which is the mean of the two values. The lower Youden pair is selected as the minimum quantifiable amount for a relevant waste effluent. This level may be from 1 to 10 ug/l. The upper level will be no higher than 500 ug/l and the intermediate level will be somewhere in between these two concentrations.

DRINKING WATER METHODS

A series of methods designed specifically for the analysis of drinking water have been developed. Primary among these are the purge and trap and liquid/liquid extraction methods for trihalomethanes (THMs) (7)(8). These methods were prepared by EMSL-CI through the collaborative efforts of chemists from the Municipal Environmental Research Laboratory - Cincinnati (MERL-CI) and the Office of Drinking Water, Technical Support Division and were published in the Federal Register as a part of an amendment to the Interim Primary Drinking Water Regulations.

The analysis of THMs is reviewed below to point out general principles of analysis for specific pollutants. Precision and accuracy is specified where possible. The THMs of primary concern in drinking water consist of chloroform, dichlorobromomethane, dibromochloromethane, and bromoform. The existing techniques for THM analysis have been reviewed by the National Academy of Science (9). Routine monitoring methods employ batch analyses, and include the purge and trap procedure (5, 10), liquid/liquid extraction (11-14), and direct water injection (15). The limitations of direct water injection have been documented by Pfaender et al.(16).

THMs are now routinely measured in many laboratories, primarily by the purge and trap (10) and liquid/liquid extraction methods (11-14).

Keith et al (17) reported that, using the purge and trap method, most of the analyses of both 10 ug/L and 1 ug/L THM standards agree within 30% of the calculated values. The variance due to instrument analysis background during routine monitoring was judged to be 0.6 and 1.7 ug/L for chloroform and bromodichloromethane, respectively. Reding et al (18) obtained comparable results regarding the overall precision of the purge and trap and liquid/liquid extraction methods for routine monitoing of THMs in drinking water at less than 1 ug/L. Single laboratory precision and accuracy developed by Bellar (7) are significantly better than this. Table VII lists data for chloroform, bromodichloromethane, chlorodibromomethane, and bromoform.

The results of interlaboratory studies conducted by ASTM committee D-19 on Water on the purge and trap technique (19) and liquid/liquid extraction (20) have been summarized (21) for chloroform, 1,2,3-trichlorobenzene and chlorobenzene (benzene and ethylbenzene were also included in the study). For the purge and trap technique over the range 2.5 to 450 ug/L, the recoveries were generally 100±20 percent. Single operator precision varied from 20 to 40 percent at the lowest concentration levels to 6 to 15 percent at the highest concentration.

The liquid/liquid extraction procedure was also recently subjected to an interlaboratory study by the ASTM Committee D-19 on Water. Two water matrices were used: a purified water and matrix water (a water simulating "natural" conditions). Bromoform, bromodichloromethane, chlorodibromomethane, chloroform, tetrachloroethylene, and 1,1,1-trichloroethane were studied.

Over the range 1.9 to 99 ug/L recoveries were from 90 to 120 percent. The relative standard deviation ranged from 10 to 27 at the lowest concentration to 3.8 to 8.0 at the highest concentration.

In addition to the THM methods, EMSL-CI has developed purge and trap methods for selected halogenated (22) and aromatic (23) compounds which are considered to be chemical indicators of industrial contamination. The methods include 47 halogenated compounds (Method 502) and 33 compounds with ionization potentials less than 10.2 eV and which are aromatic or contain a doubly bonded carbon (Method 503). Seven of these compounds are halogenated and are included in the method for halogenated compounds. The compounds are listed in Table VIII. Single laboratory precision and accuracy data for these compounds is provided in the methods.

The halogenated method employs, as its primary analytical column, a packed column of 1% SP-1000 on Carbopak-B (60/80 mesh). The column is eight feet long by 0.1 inch in inside diameter. It is operated at a helium flow rate of 40 ml/min. under programmed temperature conditions of $45^{0}C$ isothermal for 3 minutes, then 8^{0}/min to $220^{0}C$ and held at $220^{0}C$ for 15 minutes or until all compounds have eluted. An electrolytic conductivity detector operated in the halide specific mode is used for measurement.

The aromatic method uses as its primary analytical column, a packed column of 5% SP-1200 + 1.75% Bentone 34 on 100/120 mesh Supelcoport. The carrier gas is helium at a flow rate of 30 ml/min. The temperature is programmed as follows: (for lower boiling compounds) 50°C isothermal for 2 minutes, then 6°/minutes, then 6°/minute to 90°C and then held until all compounds have eluted; (for a higher boiling range of compounds) 50°C isothermal for 2 minutes, then 3°/minute to 110° and then held until all compounds have eluted. A photoionization detector with a 10.2 eV lamp is used for measurement.

Additional methods for pesticides and herbicides in drinking water are available (24). The specific compounds are noted in Table IX.

FUTURE NEEDS

Surrogate methods such as total organic halogen (TOX) and total fluorescence are desirable as class specific techniques. Such methods must measure a parameter that demonstrates a concentration relationship to the specific compounds being regulated, e.g., selected organohalogens (TOX) or polynuclear aromatic hydrocarbons (total fluorescence).

Problem areas associated with priority pollutant methods, that need to be defined are: compound stability in the matrix of interest, preservation of the sample during shipment and storage prior to analysis, allowable holding times, and emulsions. All of these problems, which vary from matrix to matrix and from source to source are currently being studied by EMSL-CI.

ANALYTICAL QUALITY CONTROL

Analytical quality control is an important aspect of any analysis. It is particularly important when the data generated are to be used in determining the health effects of the compounds measured, the effectiveness of a treatment process or compliance with regulations limiting the discharge in wastewaters or allowable concentrations in drinking waters. The quality of the data produced; the accuracy and precision with which the measurements can be made, must be known in order to reach sound decisions in these areas.

Some recommended quality control practices are presented below:

The program should consist of both intralaboratory and interlaboratory quality.

Intralaboratory Quality Control

The program must begin with intralaboratory quality control to ensure that the laboratory - the analyst - is ready to perform the analysis. This includes eliminating or, at least, minimizing all sources of determinate errors, such as, interferences from reagents, solvents, glassware, etc., i.e., the total analytical system. The operator must be well trained in the use of the method. Sample preservation and maximum holding times must also be established.

Before performing any analyses of real samples, the analyst must demonstrate the ability to generate acceptable accuracy and precision using the procedure of interest. This should be done by analyzing a minimum of four aliquots of reagent water, spiked at levels consistent with concentration range expected in the samples. The data generated: mean recovery (R) and standard deviation (s) are considered acceptable if they fall within the criteria generated by interlaboratory studies, that is, R is between the study averge recovery (X) and 100% and the standard deviation (s) is less than the study overall standard deviation (So). The interlaboratory criteria for the compounds associated with a given method are or will be published in the final methods.

Having demonstrated the ability to produce acceptable data, it is recommended that the analyst calculate and chart upper and lower control limits for use in observing trends in performance.

The analysis of duplicate (preferably field duplicates) samples is highly desirable and the analysis of spiked samples is a must. Duplicate analysis will give a measure of the reproducibility of sampling and an indication of what might be expected when samples are split for analysis between laboratories. The recoveries from analysis of spiked samples will give an indication of matrix effects. The use of surrogate spikes is also a good approach for this purpose. Duplicate and spiked sample analysis should be done at last once daily.

Additional routine quality control measures that should be practiced include: method and field blank determinations daily. A standard calibration curve must be established for each parameter and checked and updated daily.

Instrument calibrations are a must. GC retention times must be checked throughout the daily use period. For the GC-MS system, retention times and mass calibrations must be checked at least daily. The internal standard (IS) response factors must be determined and checked periodically when internal standards are used for quantification. MS criteria for identification and quantification must be defined.

Interlaboratory Quality Control

In addition to establishing the precision and accuracy of the method and routinely analyzing replicate and spiked samples, the laboratory must also analyze a quality control (QC) check sample, at least twice annually, for parameters of interest as they are available from the Quality Assurance Branch, EMSL, Cincinnati. This is in addition to the initial checks made before sample analyses begin. These quality assurance samples will be forwarded to the laboratory at the request of the responsible authority.

TABLE I. Major Classes or Organic Compounds Considered.

Purgeable Volatile
Halogenated
Non-Halogenated
Solvent Extractable Semi-Volatile
Neutrals
Bases
Acids

TABLE II. Organic Compound Classes for which Priority Pollutant Methods are Presented.

Category	Compound[a]
1	Phthalate Esters (6)
2	Haloethers (7)
3	Chlorinated Hydrocarbons (9)
4	Nitrobenzenes (3), Isophorone
5	Nitrosamines (3)
6	(2,3,7,8-TCDD)
7	Benzidines (3)
8	Phenols (11)
9	Polynuclear Aromatics (16)
10	Pesticides and PCBs (21)
11	Purgeables (29) Halocarbons (26) Aromatics (3)
12	Acrolein and Acrylonitrile

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[a] Numbers in parentheses indicate number of compounds in the category. The individual compounds are listed in Table VIII.

TABLE III. Summary of Conditions for Purge and Trap Analyses.

EPA Method No.	Parameters	Purge Temp.	Sorbent Trap	Column Packing	Gas Chromatography Temperature (°C)	Detector[a]
601	Halocarbons	Ambient	OV-1, Tenax Silica Gel, Charcoal	Carbopak-B +1% SP 1000	45 to 220	OHD
602	Aromatics	Ambient	OV-1, Tenax	5% SP 1200 + 1.75% Bentone-34	50 to 90	PID
603	Acrolein/ Acrylonitrile	85°C	Poropak-N	Chromosorb-101	100 to 140	FID

[a] Detector abbreviations:
OHD - Organohalide detector
PID - Photoionization detector
FID - Flame ionization detector

TABLE IV. Summary of Methods for Semi-Volatile Organic Priority Pollutants.

EPA Method No.	Parameter	Method	Cleanup	Column	Gas Chromatography Temperature $(^{o}2)$	Detector[a]
604	Acids Phenols	GC	Silica gel	1% SP 1240 DA, 5% OV-17	80 to 150, 200	FID, EC (Deriv.)
605	Bases Benzidines	LC	H_2SO_4	Lichrosorb RP-2	Ambient	ED
606	Neutrals Phthlates	GC	Florisil, Alumina	1.5% SP 2250 + 1.95% SP 2401	180 and 220	FID, EC
607	Nitrosamines	GC	10% HCl, Florisil, Alumina	10% Carbowax 20 M + 2% KOH	110 and 220	NPD, TEA
608	Pesticides & PCBs	GC	Florisil	1.5% SP 2250 + 1.95% SP 2401	160 and 200	EC
609	Nitroaromatics & Isophorone	GC	Florisil	1.5% OV-17 1.95% QF-1	85 and 145	EC or FID
610	Polynuclear Aromatics	LC, GC	Silica gel	HC-ODS Sil-X 3% OV-17	Ambient 100 to 280	UV, Fluorescen FID

611	Haloethers	GC	Florisil	SP 1000	60 to 230	OHD
612	Chlorinated Hydrocarbons	GC	Florisil	1.5% OV-1 + 2.4% OV-225	75 or 165	EC
613	2,3,7,8-TCDD	GC	N_aOH, H_2SO_4, Silica gel, Alumina	Silar 10C Capillary	200 to 250	MS

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[a] Detector abbreviations:
FID - Flame ionization detector
EC - Electron capture detector
ED - Electrochemical detector
NPD - Nitrogen-phosphorus detector
UV - Ultraviolet detector
F - Fluorescence detector
OHD - Organohalide detector
MS - Mass spectrometer detector
TEA - Thermal energy analyzer

TABLE V. Existing 304(h) Methods.

EPA Method No.	Parameters Measured [a]
614	Organophosphorus Pesticides (8)
615	Chlorinated Herbicides (5)
616	Benzidines (2)
617	Organochlorine Pesticides & PCBs (36)
618	Chlorinated Solvents (26)
619	Triazine Herbicides (11)
620	O-Aryl Carbamates (5)
221	N-Aryl Carbamates & Ureas (12)

[a] The numbers in parenthesis indicate the number of compounds included in the method. The individual compounds are listed in Table VIII.

TABLE VI. Additional Methods Being Proposed As 304(h) Methods.

EPA Method No.	Parameters Measured [a]
622	Organophosphorus Pesticides (19)
623	4,4'-Methylene Bis (2-chloroaniline)
626	Acrolein & Acrylonitrile (2)
627	Dinitroaniline Pesticides (5)
628	Carbofuran
629	Cyanazine
630	Dithiocarbamates (15)
631	Carbendazim and Benomyl
632	Carbamate and Urea Pesticides (7)
633	Organonitrogen Pesticides (7)

[a] The numbers in parenthesis indicate the number of compounds included in the method. The individual compounds are listed in Table VIII.

TABLE VII

Single Laboratory
Accuracy and Precision for Trihalomethanes

Parameter	Spike (µg/1)	Number Samples	Mean (µg/1)	Standard Deviation	Accuracy % Recovery
Chloroform	1.2	12	1.2	0.14	100
	12.	8	11.	0.16	92
	119	11	105	7.9	88
Bromodichloromethane	1.6	12	1.5	0.05	94
	16.	8	15.	0.39	94
	160	11	145.	10.2	91
Chlorodibromomethane	2.0	12	1.9	0.09	95
	20.	8	19.	0.70	95
	196.	11	185.	10.6	94
Bromoform	2.3	12	2.3	0.16	100
	23.	8	23.	1.38	100
	231.	11	223	16.3	97

Table VIII. List of Available Test Procedures for Organic Compounds

	Parameter	EPA Method Number[2]			
		GC	GC/MS	HPLC	Other
1.	Acenaphthene	610	625	610	
2.	Acenaphthylene	610	625	610	
3.	Acrolein	603, 626	624		
4.	Acrylonitrile	603, 626	624		
5.	Anthracene	610	625	610	
6.	Benzene	602, 503	624		
7.	Benzidine		625	605	616
8.	Benzo(a)anthracene	610	625	610	
9.	Benzo(a)pyrene	610	625	610	
10.	Benzo(b)fluoranthene	610	625	610	
11.	Benzo(ghi)perylene	610	625	610	
12.	Benzo(k)fluoranthene	610	625	610	
13.	Benzylbutyl phthalate	606	625		

TABLE VIII (Continued)

14.	Benzylchloride	618	
15.	Bis(2-chloroethyl) ether	611, 502	625
16.	Bis(2-chloroethoxy) methane	611	625
17.	Bis(2-chloroisopropyl) ether	611, 502	625
18.	Bis(2-ethylhexyl) phthalate	606	625
19.	Bromodichloromethane	501.1, 501.2, 502 601, 618	624
20.	Bromoform	501.1, 501.2, 502 601, 618	624
21.	Bromomethane	601, 502	624
22.	4-Bromophenylphenyl ether	611	625
23.	Carbon tetrachloride	601, 618, 502	624
24.	4-Chloro-3-methylphenol	604	625
25.	Chlorobenzene	601, 602, 618 502, 503	624
26.	Chloroethane	601, 502	624
27.	2-Chloroethylvinyl ether	601, 618, 502	624
28.	Chloroform	501.1, 501.2, 502 601, 618	624
29.	Chloromethane	601, 502	624

TABLE VIII (Continued)

30.	2-Chloronaphthalene	612	625	
31.	2-Chlorophenol	604	625	
32.	4-Chlorophenylphenyl ether	611	625	
33.	Chrysene	610	625	610
34.	Dibenzo(a,h)anthracene	610	625	610
35.	Dibromochloromethane	501.1, 502.2, 502 601, 618	624	
36.	1,2-Dichlorobenzene	601, 602, 612, 618, 502, 503	625	
37.	1,3-Dichlorobenzene	601, 602, 612, 618, 502, 503	625	
38.	1,4-Dichlorobenzene	601, 602, 612, 618, 502, 503	625	
39.	3,3'-Dichlorobenzidine		625	605
40.	Dichlorodifluoromethane	601, 502		
41.	1,1-Dichloroethane	601, 618, 502	624	
42.	1,2-Dichloroethane	601, 618, 502	624	
43.	1,1-Dichloroethene	601, 618, 502	624	
44.	trans-1,2-Dichloroethene	601, 618, 502	624	

TABLE VIII (Continued)

45.	2,4-Dichlorophenol	604	625	
46.	1,2-Dichloropropane	601, 618, 502	624	
47.	cis-1,3-Dichloropropene	601, 502	624	
48.	trans-1,3-Dichloropropene	601, 618, 502	624	
49.	Diethyl phthalate	606	625	
50.	2,4-Dimethylphenol	604	625	
51.	Dimethyl phthalate	606	625	
52.	Di-n-butyl phthalate	606	625	
53.	Di-n-octyl phthalate	606	625	
54.	2,4-Dinitrophenol	604	625	
55.	2,4-Dinitrotoluene	609	625	
56.	2,6-Dinitrotoluene	609	625	
57.	1,2-Diphenylhydrazine		625	
58.	Epichlorohydrin	618		
59.	Ethylbenzene	602, 503	624	
60.	Fluoranthene	610	625	610

TABLE VIII (Continued)

61. Fluorene	610	625	610
62. Hexachlorobenzene	612	625	
63. Hexachlorobutadiene	612, 503	625	
64. Hexachlorocyclopentadiene	612	625	
65. Hexachloroethane	612	625	
66. Indeno(1,2,3-cd)pyrene	610	625	610
67. Isophorone	609	625	
68. 4,4'-Methylene bis(2-chloroaniline)		623	
69. Methylene chloride	601, 618, 502	624	
70. 2-Methyl-4,6-dinitrophenol	604	625	
71. Naphthalene	610, 503	625	610
72. Nitrobenzene	609	625	
73. 2-Nitrophenol	604	625	
74. 4-Nitrophenol	604	625	
75. N-Nitrosodimethylamine	607	625	

TABLE VIII (Continued)

76.	N-Nitrosodipropylamine	607	625	
77.	N-Nitrosodiphenylamine	607	625	
78.	PCB-1016	608, 617	625	
79.	PCB-1221	608, 617	625	
80.	PCB-1232	608, 617	625	
81.	PCB-1242	608, 617	625	
82.	PCB-1248	608, 617	625	
83.	PCB-1254	608, 617	625	
84.	PCB-1260	608, 617	625	
85.	Pentachlorophenol	604	625	
86.	Phenanthrene	610	625	610
87.	Phenol	604	625	
88.	Pyrene	610	625	610
89.	2,3,7,8-Tetrachloro dibenzo-p-dioxin		613	
90.	1,1,2,2-Tetrachloroethane	601, 618, 502	624	

TABLE VIII (Continued)

91.	Tetrachloroethene	601, 618, 502, 503	624
92.	Toluene	602, 503	624
93.	1,2,4-Trichlorobenzene	612, 618, 503	625
94.	1,1,1-Trichloroethane	601, 618, 502	624
95.	1,1,2-Trichloroethane	601, 618, 502	624
96.	Trichloroethene	601, 618, 502, 503	624
97.	Trichlorofluoromethane	601, 618, 502	624
98.	2,4,6-Trichlorophenol	604	625
99.	Vinyl Chloride	601, 502	624
100.	Allylchloride	502	
101.	Bromobenzene	502, 503	
102.	2,3-Benzofuran	503	
103.	Bromochloromethane	502	
104.	p-Bromofluorobenzene	503	
105.	n-Butylbenzene	503	
106.	Sec-Butylbenzene	503	
107.	tert-Butylbenzene	503	
108.	Chlorocyclohezane	502	
109.	1-Chlorocyclohexene-1	502, 503	
110.	Dichlorodibromomethane	502	

TABLE VIII (Continued)

111.	2-Chloroethylethyl ether	502
112.	1-Chlorohexane	502
113.	o-Chlorotoluene	502, 503
114.	p-Chlorotoluene	503
115.	Cyclopropylbenzene	503
116.	p-Cymene	503
117.	1,2-Dibromoethane	502
118.	Dibromomethane	502
119.	Cis-1,2-Dichloroethylene	502
120.	1,3-Dichloropropane	502
121.	2,3-Dichloropropane	502
122.	1,1-Dichloropropene	502
123.	Isopropylbenzene	503
124.	Pentachloroethane	502
125.	n-Propylbenzene	503
126.	Styrene	503
127.	1,1,1,2 - Tetrachloroethane	502
128.	1,2,3-Trichlorobenzene	503
129.	1,2,3-Trichlorpropane	502

TABLE VIII (Continued)

130.	a-Trifluorotoluene	503
131.	1,2,4-Trimethylbenzene	503
132.	1,3,5-Trimethylbenzene	503
133.	o-Xylene	503
134.	p-Xylene	503

References

[1] For methods 601-613, 624 and 625, see Federal Register, December 3, 1979 (3). For the remaining 600 series methods, see "Proposed Amendments to 304(h) Methods for Municipal and Industrial Effluents, January 1980," available from Director, Environmental Monitoring and Support Laboratory, USEPA, Cincinnati, Ohio 45268. For 501.1 and 501.2 see Federal Register, November 29, 1979 (23). Methods 502 and 503 are in review.

Table IX. List of Available Test Procedures for Pesticides[a]

	Parameter	EPA Method Number[b] GC	GC/MS	Other	Additional Procedures
1.	Aldrin	608,617	625		c, e, f, i
2.	Ametryn	619			
3.	Aminocarb			620	
4.	Amobam			630	
5.	Atraton	619			
6.	Atrazine	619			
7.	Azinphos methyl	614,622			
8.	Barban			621	
9.	Benfluralin	627			
10.	Benomyl			631	
11.	a-BHC	608,617	625		c, e, f, i
12.	b-BHC	608,617	625		c, e, f, i
13.	d-BHC	608,617	625		c, e, f, i
14.	g-BHC	608,617	625		c, e, f, i
15.	Bolstar	622			
16.	Bromacil	633			
17.	Busan 40			630	
18.	Busan 85			630	
19.	Captan	617			c, i
20.	Carbaryl			620	
21.	Carbendazim			631	
22.	Carbofuran			628	
23.	Carbophenothion	617			f
24.	Chlordane	608,617	625		c, e, i
25.	Chlorobenzilate	608[h]			
26.	Chloroneb	608[h]			
27.	Chloropropylate	608[h]			

TABLE IX. (Continued)

28.	Chlorpropham			621	
29.	Chlorpyrifos	622			
30.	Coumaphos	622			
31.	Cyanazine	629		629	
32.	2,4-D	615			d, g, i
33.	2,4-DB	615			
34.	4,4'-DDD	608,617	625		c, e, f, i
35.	4,4'-DDE	608,617	625		c, e, f, i
36.	4,4'-DDT	608,617	625		c, e, f, i
37.	Deet	633			
38.	Demeton-O	614,622			
39.	Demeton-S	614,622			
40.	Diazinon	614,622			f
41.	Dibromochloropropane	608[h]			
42.	Dicamba	615			i
43.	Dichlofenthion	614			f
44.	Dichloran	617			c, i
45.	Dichlorvos	622			
46.	Dicofol	617			e
47.	Dieldrin	608,617	625		c, e, f, i
48.	Dinoseb	604[h]			
49.	Dioxathion	614			f
50.	Disulfoton	614,622			
51.	Diuron			632	
52.	Endosulfan I	608,617	625		c, e, i
53.	Endosulfon II	608,617	625		c, e, i
54.	Endosulfon sulfate	608,617	625		
55.	Endrin	608,617	625		c, e, f
56.	Endrin aldehyde	608,617	625		
57.	Ethalfluralin	627			
58.	Ethion	614			f
59.	Ethoprop	622			
60.	Etridiazole	608[h]			

TABLE IX. (Continued)

61.	Fensulfothion	622			
62.	Fenthion	622			
63.	Fenuron			621	
64.	Fenuron-TCA			621	
65.	Ferbam			630	
66.	Fluometuron			632	
67.	Heptachlor	608,617	625		c, e, f, i
68.	Heptachlor epoxide	608,617	625		c, e, f, i
69.	Hexazinone	633			
70.	Isodrin	617			f
71.	Isopropalin	627			
72.	KN methyl			630	
73.	Linuron			632	
74.	Malathion	614			c, f
75.	Mancozeb			630	
76.	Maneb			630	
77.	Merphos	622			
78.	Metam			630	
79.	Methiocarb			620	
80.	Methomyl			632	
81.	Methoxychlor	617			c, e, f
82.	Metribuzin	633			
83.	Mevinphos	622			
84.	Mexacarbate			620	
85.	Mirex	617			c, i
86.	Monuron			621	
87.	Monuron-TCA			621	
88.	Nabam			630	
89.	Naled	622			
90.	Neburon			621	
91.	Niacide			630	
92.	Oxamyl			632	
93.	Parathion methyl	614,622			c, f
94.	Parathion ethyl	614			c

TABLE IX. (Continued)

95.	PCNB	608[h],617			c, i
96.	Perthane	617			e
97.	Phorate	622			
98.	Polyram			630	
99.	Profluralin	627			
100.	Prometon	619			
101.	Prometryne	619			
102.	Propachlor			632	
103.	Propazine	619			
104.	Propham			621	
105.	Propoxur			632	
106.	Ronnel	622			
107.	Secbumeton	619			
108.	Siduron			621	
109.	Simetryne	619			
110.	Simazine	619			
111.	Sodium dimethyl dithiocarbamate			630	
112.	Stirophos	622			
113.	Strobane	617			c, e, i
114.	Swep			621	
115.	2,4,5-T	615			d, g, i
116.	2,4,5-TP	615			d, g, i
117.	Terbacil	633			
118.	Terbuthylazine	619			
119.	Terbutryn	619			
120.	Thiram			630	
121.	Toxaphene	608,617	525		c, e, f, i
122.	Triadimefon	633			
123.	Trichloronate	622			
124.	Tricyclazole	633			
125.	Trifluralin	617,627			i
126.	Zineb			630	
127.	Ziram			630	

Footnotes

a. Pesticides are listed in this table by common name for the convenience of the reader. Additional pesticides may be found under Table 1c, where entries are listed by chemical name.

b. For methods 601-613, 624 and 625, see the Federal Register, December 3, 1979 (3). For the remaining 600 series methods, see "Proposed Amendments to 304(h) Methods for Municipal and Industrial Effluents, January 1980," available from the Director, Environmental Monitoring and Support Laboratory, U.S.EPA, Cincinnati, Ohio, 45268. For 501.1 and 501.2 see Federal Register, November 29, 1979 (23). Methods 502 and 503 are in review.

c. Standard Methods for the Examination of Water and Waste Water, 14th Edition, 1976, Method 509A.

d. Ibid, Method 509B.

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h. Cited method does not state applicability to these compounds, but direct gas chromatography approach can be used.

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NONSPECIFIC ORGANIC ANALYSIS OF WATER FOR REUSE FACILITIES

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NONSPECIFIC ORGANIC ANALYSIS OF WATER FOR REUSE FACILITIES

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Nonspecific organic analyses are the collective measurement of a large number of organic compounds by a particular analytical method. The principle analyses that have been utilized routinely for measurement of nonspecific organic compounds are shown in Table 1. The purpose of nonspecific organic analysis (es) should be defined in terms of specific goals. These goals could include one or more of the following:

1. To develop a surrogate parameter for specific organic compounds of health concern.
2. To aid in the design of a unit treatment process.
3. To monitor a unit process(es) or a treatment plant.
4. To be used in operational control of a unit process or a treatment plant.

Nonspecific organic analyses can be used to measure loading and time changes of organics in influent and/or effluent waters. It is quite probable that nonspecific methods for organic compounds will provide essential date for design, monitoring and control in direct reuse situations. The extent to which these methods are used for the above purposes will depend on the development of instrumentation which is reliable, provides on-line measurements and is economically feasible.

Nonspecific analyses have been used in reuse research and correlations with specific organic compounds are being attempted. Elementary general organic and spectroscopic analyses have been tested extensively by several investigators in an attempt to replace or supplement the complex gas chromatographic or gas chromatographic/mass spectrometric analytical procedures. Correlation among these analyses and organic compounds with possible health effects has been attempted in order to develop an economical and rapid monitor for use in treatment processes. Design, monitoring and operational use, as well as development of surrogate parameters, will be discussed in each section.

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Philosophical Approach

In order for water reuse to be accepted as a source of potable water the need for stringent control of organic contaminants will be necessary. It is obvious from the expense, in equipment and personnel, that it may not be possible to meet the above by routinely monitoring each specific organic compound (e.g. priority pollutant analysis). Indeed, it is the premise of this section that in a well characterized and designed reuse system of the future, specific priority pollutants may need only be occasionally monitored. The frequency will depend on the variability of the source and reliability of the treatment process. Further monitoring by specific analytical procedures could be dictated by excursions from preset limits as measured by nonspecific on-line procedures and broad spectrum chromatographic profile methods described elsewhere (1). The preset limits would be developed in the design stage of a reuse facility.

It should also be pointed out that nonspecific procedures are envisioned as generally less expensive and less skill-level dependent than methods for the determination of individual organics by techniques such as gas chromatography/mass spectrometry.

The automation of procedures is of paramount interest for several reasons. Once a procedure is automated, then, although the initial expense of equipment may be somewhat higher, the cost of manpower is reduced, thereby reducing the per-sample cost proportionately and increasing the frequency of data collection. It is equally important that emphasis be given to those procedures which can be modified to give on-line or continuous measurements of water quality.

Table 1. EXAMPLES OF NONSPECIFIC MEASUREMENTS OF ORGANIC CHEMICALS

I. Elemental Parameters	Organic Carbon Organic Halogen
II. General Organic Parameters of Response	Biochemical Oxygen Demand (BOD) Chemical Oxygen Demand (COD) Total Oxygen Demand (TOD) Elecrochemical Organic Content (EOC
III. Spectroscopic Response for the Double Bond, Aromatic Organic Compounds or Unshared Electrons	Ultraviolet/Visible Absorption Fluorescence
IV. Analysis of Chemical Classes (Functional Group Analysis)	Cholinesterase Inhibitors (Organophosphorus and Carbamate Pesticides), Amines, Carbohydrates, Acids
V. Precursor Analysis	Trihalomethane Formation Potential (THMFP)

I. Elemental Parameters

Total organic carbon (TOC). A well-known example of element analysis is the measurement of total organic carbon. Theoretically this measurement would give an indication of the total organic contribution in a water. Dissolved organic carbon (DOC) is usually defined as the total measurement after passage through a 0.45 micron filter. Purgeable organic carbon (POC) is that which can be stripped from an aqueous solution at ambient temperatures in 2.5 minutes and nonvolatile TOC (NV TOC) that which is the organic carbon left after purging.

Practical considerations account for less than ideal measurement of total organic carbon. Either not all carbon containing organics respond totally or inorganics interfere with the measurement. Recent improvements in methodology appear to have resulted in more sensitivity and higher reliability. Ultraviolet oxidation is one of the new techniques gaining acceptance. Originally developed for determination of organic matter in the oceans (2) it has been modified for use in water and wastewater (3). Once the organic carbon is converted to CO_2 it can be measured either by an infrared detector, reduced to CH_4 and burned in a flame ionization detector or measured conductometrically.

Known specific organic compounds of health concern have been estimated to be less than 10 percent of the organic content of drinking water (4,5). Therefore, total organic carbon measurements are not considered to be a valuable surrogate parameter for these compounds. Information on TOC is necessary for engineering design of treatment processes and understanding pilot plant processes, e.g. loading of organics on granular activated carbon

(GAC) filters. The use of the TOC measurement for monitoring and operational control is being studied.

Correlation between other surrogate analyses; e.g., BOD and TOC, have been established in municipal wastewater (6). The use of TOC for monitoring carbon adsorption as a unit process has been reviewed (7). Nonvolatile TOC has been shown to be a "reasonable indicator" for the production of trihalomethanes in the 80-city survey conducted, whereas the total TOC does not appear to be as good a predictor (8). Organic carbon analyses and UV absorbance have been used for process control of GAC plants in the Federal Republic of Germany (9). The ratio of DOC to UV absorbance was found to change after different water treatment processes. For drinking water, the NV TOC method did not correlate well with the UV absorbance method of Dobbs et al. (10), the fluorescence method of Sylvia (11,12), or an emission flourescence scanning method (12).

Sylvia and Donlan demonstrated a correlation between TOC and fluorescence from numerous water sources (13). This is comparable with data of Snoeyink et al (14), who reported that fluorescence could be used to monitor adsorption of the lower molecular weight fraction of humic material. The EPA has stated that TOC tends to give excessive weight to naturally occurring high molecular weight compounds, which are not believed to be hazardous, and that TOC is not a suitable criterion for the design of GAC systems (15). Breakthrough of specific organic compounds on GAC columns and breakthrough by nonspecific organic parameters of TOC, fluorescence and UV absorbance were not successfully correlated (16,17,18).

Total organic carbon has been used as one of several methods of monitoring in wastewater treatment and reuse in a groundwater recharge project (19).

On-Line TOC/COD. A research project, presently in progress, has as its objective the development of an on-line continuous monitor for the determination of TOC (20). This procedure utilizes the in-situ generation of persulfate (electrochemically) with the oxidation of the organics aided by UV. The CO_2 is then detected by a pCO_2 electrode. This development is continuing and has been jointly sponsored by DoD and EPA.

The basic goal is the on-line continuous measurement of TOC and COD. The principle used was the in-situ generation of persulfate (S_2O_8) electrochemically. The organics present are oxidized using the persulfate catalyzed by UV, the CO_2 evolved was measured by an electrode to give TOC and the difference in S_2O_8 concentration is the COD (20-23).

This project is in the final stages of development at the breadboard TOC/COD instrument level. It has been shown that a reliable TOC measurement can be obtained. The COD measurement has presented several technical problems for which alternatives exist but may not be solved during the present development.

Instrumentation of this type will be imperative when reuse systems are used because of their ability to monitor the quality of effluent and their potential use as automatic process control instrumentation.

On-Line TOC Water Quality Monitor. As part of the Regenerative Life Support Evaluation Program within NASA a preprototype Water Quality Monitor subsystem was developed. As a portion of the project an on-line TOC analyzer was built (24-26).

The sample, reagent and standards are pumped continuously with a peristaltic pump. The TOC reading is observed using an electrode after the sample has been oxidized with UV and peroxymonopersulfate (HSO_5^-) or peroxydisulfate ($S_2O_8^=$).

The design goal for the TOC was 1 to 100 mg/L ± 10 percent or ± 1mg/L, whichever is greater, response time five minutes with 30 days continuous operation.

It was shown that the peroxymonopersulfate gave incomplete conversion of acetic acid, phenol and p-cresol. The peroxydisulfate ($S_2O_5^=$) was found to slowly decompose to peroxymonopersulfate (HSO_5^-). Although both are oxidants and activated by UV, the former is stronger and will oxidize completely those compounds not oxidized by HSO_5^-.

A positive interference by Cl^- was observed as reported elsewhere (22). However, at the expected concentrations of no greater than 12 mg/L it was shown to be negligible.

This program has shown the fesibility for on-line continuous measurement of TOC. Again, additional work is necessary to provide instrumentation for routine use.

Thus, monitoring of TOC or various portions thereof, during a reuse treatment scheme, should be considered. As a process monitor, TOC does indicate changes of influent concentration, process trends and general organic changes to help design, monitor and possibly operate a unit process or treatment plant. The reliance on such a parameter may very well depend on the availability of low-cost, continuous monitors.

Organohalides (OX). Lower molecular weight organic compounds containing halogens are one of the most prevalent class of compounds on the lists of organics of health concern (4,5,27) and are presumably prevalent in waters under consideration for reuse. Higher molecular weight organics containing halogens from partially chlorinated humic material are also suspected of having implications for health (5).

Methods for the determination of individual organohalides have been developed using purge and trap techniques (28,29) and solvent extraction (30,31). An excellent review of the historical aspects of measurement of OX has recently appeared and serves as the basis of this section (34). Standardized definitions of terms were developed in the above report. The other abbreviations would be OX to indicate measurement of organohalides as a group, POX to indicate the purgeable fraction of OX, and NPOX to indicate the non-purgeable fraction of OX (33).

The first method for determining OX utilized ground granular activated carbon in a 10 L water sample (35,36). The carbon was pyrohydrolyzed (using superheated steam and oxygen) to convert organochlorine compounds to HCl. The Cl^- was then determined using a selective ion electrode. This procedure required long analysis times and an elaborate blank determination. The procedure was modified by using microcoulometry for Cl^- measurement, inorganic Cl^- was excluded from adsorption by the addition of NO_3^- to the sample (37). More recently the methodology has been developed into a small batch extraction method using a minicolumn (38,39). Macroreticular resins (XAD series) have also been used for OX measurement (40) as has been flash vacuum-evaporation (41) and neutron activation followed by gamma ray spectroscopy (42). The aspect of extractable organic chlorine (EOCl) has been suggested as a measure of chemical pollution (43).

Steiglitz et al. (44) reported that single substance analysis of Rhine River water by GC and GC/MS, and elemental analysis by TOX indicates that only approximately 10 percent by weight of the dissolved organic halogen (DOX) was identified by GC/MS analysis. There was no recognizable correlation between the concentration of DOX and the amounts of specific organics. Kuhn and Fuchs (45), Sanders et al. (46), and Oliver (47) showed that DOX increases after chlorination of natural water as do the THM's. The THM's do not account for all of the increase. THM's have been shown recently to account for up to only 25 percent of the OX in drinking water (48).

From the review of the methods (34) and the improvements reported therein, the method using a carbon column for adsorption with subsequent pyrolysis appears to be the method of choice. However, very stringent techniques are required to ensure accurate results and to minimize the blank. The limit of detection is reported to be 5 ug/L. The method is being tested and will undergo additional procedural improvements.

In summary, the determination of OX, POX, NPOX are going to be important parameters where water for potable reuse is of concern. Organohalide monitoring may provide information of health concern on synthetic organic chemical as well as formation of low and high molecular weight organochlorine compounds when using chlorine as the disinfectant. The development of on-line instruments should be considered in the future.

General Conclusions

The elemental analyses indicate changes of influent concentration, process trends, and general adsorption capabilities. The carbon adsorbable OX as Cl measurement could be a nonpecific analysis of choice, as many organics of potential harm to health are halogenated. The other purposes of design, pilot plant understanding, operational control and monitoring of a unit process will evolve from the interest in organics of health concerns.

II. General Organic Parameters

Biochemical Oxygen Demand, five days (BOD 5) and Chemical Oxygen Demand (COD). In the field of wastewater treatment, BOD_5 and COD have been traditional design parameters and measurements of plant effectiveness. Even with their problems, length of analysis and only mediocre precision, they remain one of the parameters that engineers use in design and enforcement agencies use in regulations. In monitoring water intended for reuse, the BOD_5 and COD test will have little or no value because of the time needed to obtain a measurement. (This of course might not be true if lengthy detention times are incorporated into the design). A reasonable goal for reuse would be to limit or eliminate their use entirely, replacing them with other easier and more reliable measurements. Because BOD_5 does take five days, the test could never be used as a control parameter.

Total Oxygen Demand (TOD). The total oxygen demand test monitors the total oxygen needed to oxidize organic and inorganic species in a water (49). Its use has been very limited by municipal wastewater treatment plants because of the cost of instrumentation, the fact that it was designed primarily for industrial effluent (not amenable to BOD_5) and that it is not a standard test. It is possible that, were more inexpensive instrumentation to become available, this procedure would be utilized in water reuse. Presently, analysis times of a few minutes are short enough that a control function using TOD could be integrated into processes.

Electrochemical Organic Content (EOC). It has been shown that when an electrode was immersed in an aqueous solution at a given potential that the interfacial capacitance could be measured. Further, it was theorized and proven that the interfacial capacitance could be obtained for organic compounds in aqueous solution. The name given to the analyzer was the electrochemical organic content (EOC) analyzer (50-55).

The basic operation of the instrument is as follows: The cell consists of three electrodes, using a reference electrode for potential adjustments and a counter electrode for measurement of organics. A minicomputer was employed in order to enable various adsorption potentials to be tested. An on-line capability has been developed for the EOC. The counter electrode is automatically conditioned by an oxidation stage followed by reduction stage. The length of each stage can be set by adjusting a multiturn potentiometer.

Both the US Army and NASA joined in the development of this analyzer; however, because of funding priority shifts, were not able to develop it beyond breadboard instrumentation. It was shown that the EOC did respond to various organics to a greater or lesser extent. It was also shown that a correlation between the concentration of organics and EOC reponse existed. Several of the problems encountered were lack of sensitivity to several compounds expected in reverse osmosis permeates from synthetic Army hospital wastes and a positive Cl^- interference.

From the experience gained it was felt that the analyzer could potentially be useful in reuse processes where a general organic water quality indicator is needed. By employing several cells with adsorption potentials set at different levels one could also obtain a qualitative estimation of the organic loading. Further work needs to be conducted in this area to provide data on natural waters as well as to better define the limitations of instrumentation of this type.

In summary, whereas BOD_5 and COD do not hold promise as monitoring or control parameters, TOD and EOC are of potential use. Additional work is needed in both areas (TOD and EOC) in order to provide reliable low cost instrumentation.

III. Spectroscopic Measurements

The use of spectroscopy for structural elucidation of organic compounds is very well documented. It is, therefore, not surprising to see the use of ultraviolet (UV) and fluorescence detection extended to monitoring organics in natural waters. UV and fluorescence measurements respond to conjugated double bonds, aromatic organics and unshared electrons. These methods are a function of both the concentration and type of species present and without further chemical characterization of the sample cannot be used to completely delineate chemical systems. But the use of these methods to follow humic (precursor) material which have spectroscopic characterization and aromatic pollutants is a possiblity.

Ultraviolet. The absorption in the range of 200-300 nm is primarily due to organic compounds having aromatic or conjugated unsaturated structures (56,57). UV absorbance is subject to interferences from some inorganic compounds. Nitrate absorbs at approximately 210 nm (57) as does bromide. Bromide does not interfere at wavelengths above 250 nm (58).

Some organic compounds which do not absorb in the UV are also the ones most rapidly consumed by microorganisms (10). Many wavelengths have been studied. The absorbance at 275 nm has been correlated to the permanganate consumption value (10,59). Absorbtion at 250 nm has been recommended as a potential for evaluating removal of soluble trace organics by physicochemical treatment (10). Coke oven plant wastes and water from Lake Michigan have been monitored using 254 nm (56).

It has been suggested that the dissolved organic substances in natural waters can be classified according to absorbance ratios (58). Other wavelengths have been used for various purposes for monitoring water (59-63).

Correlation of a measurement at 254 nm and total organic carbon in various treated and untreated water samples has been described (10). Because of a plateau in the spectra from 240 to 270 nm, the spectral line at 254 (253.7 nm) of low pressure mercury lamps was chosen for study and an on-line organic pollutant monitor was proposed based on this work (64). A correlation was obtained with BOD, COD and TOC for a wide range of waters.

The UV absorbance together with dissolved organic carbon and total organic carbon have been suggested as the most unspecific organic analyses (65). The use of 254 nm has been proposed as a means of monitoring surface waters to detect (immediately) accidental organic pollution (66). The concentration of total organic carbon may be estimated from UV absorbance at 250 nm in unpolluted stream water (67). The absorbance at 254 has also been used in evaluating the performance of activated carbon (19).

It has been suggested 274 nm be used for measuring organic compounds (68). Recent results showed that monitoring at UV $_{254}$ correlated absorbance (UV_{254}-UV_{545}) a better correlation to other standard procedures was obtained. It has also been shown that a single wavelength does provide a measurement which is correlated with the organic loading of water intended for reuse (19).

The advantages to this procedure are the short times required to obtain spectra and instantaneous values at specific wavelengths. A disadvantage is the significant interferences from turbidity (suspended material).

Another approach using UV measurements has been used to characterize the organics in river water (69). The approach used was a multiwavelength analysis. A number of model compounds were employed to develop a matrix of spectra vs. compound. This data was then analyzed using a computer. From the simulation tests it was shown that it was possible to obtain an algorithm that calculated the match of absorbance spectrum in multicomponent mixtures and concentrations of individual compounds from the absorbance spectra.

This method was then applied to a river water (upper reaches of the Mississippi) after a molecular weight fractionation of the water. Five of the model compounds were identified: vanillin, 3,4 dimethoxy acetophenol, tannic, p-anisic and mellitic acid, by UV absorbance computer matching calculations. The widespread use of this method in river water with the variability of humic materials is questionable, but further research should be conducted to see if this method could be used in a defined treatment system.

Fluorescence. A technique has been described using fluorescence (11,12,13). The fluorescence method was originally developed to evaluate the efficiency of carbon columns in the removal of the carbon chloroform extract from treated drinking water.

To obtain the reading, the water sample was excited at 320 nm and the fluorescence emission read at 390 nm. This method referred to as the Rapid Fluorometric Method, could "be applied to the detection of trace organics in drinking water" and correlated well with humic materials as previously described.

The Rapid Fluorometric Method appears to have several advantages that provide a basis for further study. The method does have reasonably good sensitivity (more than UV methods), it is adaptable to on-line monitoring and also it can be used as a monitor for specific pollutants by optimizing the excitation wavelength and emission wavelength for specific compounds.

Summary. This section has dealt with nonspecific spectroscopic methods that could be utilized as indicators of the change of organics through a treatment system.

Spectroscopic technicques may offer simple procedures for screening the quality of source water and water through the treatment processes. It also can indicate when a spill up-stream or other perturbation in water quality has occurred. This, in turn, would signal that more extensive sample characterization is needed.

With the advent of new microcomputer controlled UV/Vis spectrophotometers, routines have been included to perform spectra matching and deconvolution automatically.

Correlation of Nonspecific Organic Analyses. There have been a number of studies which have attempted to correlate various organic parameters in the first three categories. The most comprehensive was a recent study on water intended for reuse which has provided very interesting data (16). Some of the results of that study are summarized in Tables 2 and 3 for raw and secondary effluent.

It is obvious that the various parameters can be correlated to varying degrees. The important point is that these correlation provide the basis for more extensive development of techniques to rapidly assess water quality.

Correlation which have neither been successful or fully developed are those between nonspecific analyses and chemicals of concern to health. The measurement of OX may in the future be such a nonspecific parameter. Work should be initiated in this area.

TABLE 2. SIMPLE CORRELATION COEFFICIENT (r) BETWEEN GROSS ORGANICS PARAMETERS (16)

RS - Raw Sevage (South)

	BOD	COD	$KMnO_4$	TOC	DOC	UV	UV'
BOD	1.000						
COD	0.634	1.000					
$KMnO_4$	0.554	0.862	1.000				
TOC	0.654	0.846	0.829	1.000			
DOC	0.545	0.414	0.633	0.579	1.000		
UV	0.790	0.891	0.919	0.838	0.666	1.000	
UV'	0.959	0.896	0.969	0.911	0.685	-	1.000

RS_2 - Raw Sewage (North)

	BOD	COD	$KMnO_4$	TOC	DOC	UV	UV'
BOD	1.000						
COD	0.710	1.000					
$KMnO_4$	0.623	0.888	1.000				
TOC	0.736	0.885	0.936	1.000			
DOC	0.622	0.671	0.822	0.906	1.000		
UV	0.596	0.832	0.666	0.735	0.519	1.000	
UV'	0.707	0.940	0.945	0.993	0.984	-	1.000

TABLE 3. SIMPLE CORRELATION COEFFICIENTS (r) BETWEEN GROSS ORGANICS PARAMETERS (16)

SE_2 - Secondary Effluent (Act. Sludge)

	BOD	COD	$KMnO_4$	TOC	DOC	UV	UV'
BOD	1.000						
COD	0.573	1.000					
$KMnO_4$	0.682	0.711	1.000				
TOC	0.481	0.781	0.787	1.000			
DOC	0.445	0.729	0.548	0.681	1.000		
UV	0.776	0.876	0.930	0.681	0.578	1.000	
UV'	0.743	0.695	0.906	0.873	0.897	-	1.000

$UV' = UV_{254} - UV_{545}$

IV. Analysis of Chemical Classes of Organic Compounds (Functional Group Analysis)

Many methods are available for the determination of organic compounds which are specific for classes of compounds. These methods have been used in classic qualitative organic chemistry determinations (70). The adaptation of chemical class analysis of this type to the analysis of very low levels of compounds in water requires considerable development; however, it can be done.

Primary Amines. In a recent paper a method was described which has been adapted for the determination of primary amines in river water (71). The method uses fluorescence (4-phenyl-spiro [furan-2(3H),1-phthalon] 3,3'drone) the intermediate in the ninhydrin reaction (72,73). It has been shown that the fluorescence method was linear through the concentration range 0.5 to 5 uM. The limit of detection for glycine was 0.2 uM (20 ug). This analysis was extended to fractionated (by ultrafiltration into molecular weight fractions) river water. The authors were able to demonstrate the existence and relative distribution of amines in the natural water. The method has a potential as a rapid screening procedure for primary amines. Primary amines could potentially be used as a control parameter for biological processes as they constitute a portion of the natural metabolic end products.

Carbohydrates. With recent improvements of the anthrone method (74) a qualitative method has been developed for carbohydrates in river water (73). The method involves the addition of the anthrone reagent to a highly acidified sample of water. The anthrone is reasonably labile and therefore has to be made fresh (within four hours). Using glucose as the carbohydrate standard the procedure was shown to obey Beers Law through 20 mg/L (0.11 mM) with a sensitivity of 1 mg/L (0.0056 mM).

Until reagent stability is increased, it is unlikely that this method could be used as an on-line continuous technique. It does appear, however, that this procedure could be used as a screening method for carbohydrates.

Acids. Maier et al. (79) have developed a procedure to analyze total organic acids by weekly composites after adsorption on carbon, desorption by dimethyl formamide (DMF) and subsequent titration. The approach has also been applied to carbon from working GAC filters. This area of work is only in its infancy and needs continued development.

Cholinesterase Inhibitors. The mode of action of most organophosphate and carbamate pesticides in inhibition of the enzyme cholinesterase, an essential component in animal nervous systems. Many of the compounds (pesticides) can be determined using gas chromatography. However, for the purpose of this discussion, the total enzyme inhibition is of interest.

A standard method is available for the determination of total cholinesterase inhibition (Standard Methods, 14th Ed., p 570). This procedure is applicable to waters intended for reuse. This measurement will be one which is necessary for total characterization of unit processes and may find application in monitoring. Because of the chemical degradability of most organophosphate and carbamate pesticides these are not likely to be encountered through a reuse treatment system.

Summary. Many analytical procedures are available which are class specific, e.g. amino acids or cholinesterase inhibitors. The adaptation of chemical class analysis at very low levels of compounds in aqueous systems requires considerable development. This may be another monitoring approach for treatment design and process control. Cholinesterase inhibition is a surrogate for chemicals of health concern e.g. organophosphate and carbamate pesticedes.

V. Precursor Analysis

Precursor chemicals are those that react with disinfectants to produce byproducts, Rook (80) and Bellar et al. (28) reported that chloroform and other THM's in finished drinking water occurred as a result of chlorination of the water containing the precursors. In the presence of residual chlorine THM concentrations have been shown to increase as the water flows through the water treatment plant and through the distribution system (81). A functional precursor definition, the THM formation potential (THM FP), has been defined to determine the maximum THM concentration under appropriate test conditions which can be developed for each water supply. THM FP, therefore, is a measure of potential precursors of haloforms (81). The removal of precursors by water treatment processes, including adsorption processes, has been studied during pilot plant tests (17-19).

The THM FP method is an obvious measure to evaluate a process. Products of water treatment processes that may be of health concern may be approached by first developing formation potential measurements. However, because of the lenght of time for the analysis this is not likely to be acceptable from a regulatory or control standpoint, a quicker estimation method is needed. A recent publication (82) utilizing I_2 instead of Cl_2 been has proposed and deserves further study. The advantage appears to be a shorted reaction time.

VI. Data Acquisition, Monitoring and Control Instrumentation.

Although many industries (the petroleum refining industry is an example) make extensive use of monitoring and control instrumentation, the water and wastewater industries have not for the most part adopted this mode of operation. Because in a reuse situation control of the plant will be critical to insure a consistently high quality product it may be that sophisticatd computer control should be adopted.

Research will provide models which are and will be refined. These models will provide the asis for computer control. At the pilot plant scale, the integration of a data aquisition system with both a monitoring and control capability has been accomplished. The instrumentation was characterized by: (83)

1. Computerized, automatic process parameter control.
2. Automatic operating mode control.
3. Automatic operating mode transition control.
4. Automatic setpoint modification.
5. Fault detection and isolation analysis.
6. System performance trend analysis.
7. Interactive operator/system interface.
8. Automatic data transmission to data aquisition system.

It was concluded that computer-based instrumentation is a viable solution to controlling the complex mechanical/electrical system (84-90).

It is at this point where the need for automated reliable and on-line instrumentation becomes apparent. In order to have a computer-based monitor and control operation, it is necessary to have the appropriate sensors.

Several of the techniques for determining general organic parameters have been or could be automated. However, more work is needed in this area of automating chemical analysis and integrating data aquisition systems withe monitoring and control functions.

Discussion

Nonspecific organic analyses are not recommended as surrogate parameters for specific organic compoounds of health concern. Correlations as yet do not exist for this purpose. Cholinesterase inhibition and THM FP are nonspecific parameters directly related to health effects. But, since THM FP takes greater than 3 days to run, a quicker estimation method is needed.

Nonspecific organic analysis is best utilized to aid initial design of treatment facilities as these methods, complemented by specific organic chemical analysis, can indicate mass loading of organics, the presence of aromatics, functional groups, chemical classes, and precursors of chemicals of concern to health. To date, organic carbon and halogen, and UV and fluorescence methods have been developed for multiple analysis. Further developments are needed to bring the other nonspecific organic analysis up to the speed and ease of operation of these measurements.

Monitoring operational treatment processes is a site specific consideration based upon initial survey data and the final purpose of water use. Operational control will sequentially follow from the monitoring effort. Nonspecific organic analysis may be developed as a screening method for spills and signal the need for individual analysis.

Of the several million organic chemicals synthesized, many have been identified in water reuse situations and approximately 129 have been slated for regulation as priority pollutants (91). The widely varying concentrations and complex matrices make the quantitative determination of even these few chemicals a formidable task. Process control in wastewater or water treatment based on routine monitoring for individual compounds is far too costly at present. Thus, in the next ten years it is felt nonspecific procedures and broad spectrum chromatographic profile methods will be used for operational monitoring and control of reuse facilities, leaving analyses for less than routine samples and situations where these methods indicate a problem situation. The objectives of using these procedures is to provide as much continuous monitoring of the organic loading as possible. It is not likely to ever replace the need for detailed characterization of the organic compounds in a water for reuse. They can only help control the monitoring process. Since a continuous reading is best, it will be necessary that the instrumentation for non-specific measurement to be low in cost, reliable and capable of unattended operation and automatic calibration.

New approaches are specifically needed for nonspecific analysis of organics. An example is the pervaporation method of Mieure (92,93). It has been shown that pervaporation through a hollow fiber is a method for introducing volatile compounds from water into a mass spectrometer (92). Based on this and the use of a membrane separator (normally used to interface a gas chromatograph and mass spectrometer) a procedure was developed to exclude water from a mass spectrometer while allowing organics solutes to enter the mass spectrometer (93). The mass spectrometer was used in the selective ion monitoring mode with electron impact ionization.

This method appears to have the capability of near on-line monitoring for specific compounds providing that a suitable ion(s) could be found. By monitoring multiple ions (e.g. chlorine isotope ions) a nonspecific indication of VOX could be obtained. Classes of compounds could also be monitored where an ion(s) is class specific. It is quite possible that this instrument could be used in waters intended for reuse. This procedure would be particularly useful if several compounds could be used as tracers through unit processes. The big disadvantage would be the cost of a mass spectrometer. However, small quadrupole mass spectrometers capable of measuring limited mass numbers could be built strictly for monitoring, at far less expense than general purpose mass spectrometers. Other innovative approaches in this area should be developed.

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CONCENTRATION OF ORGANIC COMPOUNDS IN WATER FOR BIOASSAY METHODS AND TOXICITY TESTING. A LITERATURE SURVEY*

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INTRODUCTION

Before trace amounts of organic constituents that are in aqueous solutions as complex mixtures can be analyzed, the solutions must be concentrated. This is necessary so that a sufficient mass of organics can be obtained for separation and subsequent identification. An analogous situation exists for determining the biological activity of such unknown or mostly unknown trace organic constituents in waters of environmental or public health concern. This is especially true for biological testing of long duration or testing that requires many large test species.

The choice of method or combination of methods for concentration is dependent on such factors as volatility of the organic constituent to be tested, the degree of concentration required, and the biological test system to be used.

Kopfler (1980a) divides concentration methods into two basic categories:

1. Concentration; that is, those processes in which water is removed and the dissolved substances are left behind. Examples are freeze concentration, lyophilization (freeze drying), vacuum distillation, and membrane processes such as reverse osmosis and ultrafiltration. A common disadvantage to these methods is that inorganic species are concentrated along with the organic constituents.
2. Isolation; that is, those processes in which the organic substances are removed from the water. Examples are solvent extraction and adsorption on resins.

CONCENTRATION TECHNIQUES

FREEZE CONCENTRATION

In the freeze concentration process, a portion of the water sample is frozen which concentrates the dissolved substances in the unfrozen portion (Shapiro, 1961; Baker, 1969, 1970). In this process, Baker demonstrated 80% recovery of *m*-cresol (initial concentration, 310 ppm) with a 20-fold volume reduction. Generally, recovery of organic constituents decreased with increasing inorganic concentration. The method was laboratory tested for milliliter volumes. Commercial equipment is not currently available.

LYOPHILIZATION

In the lyophilization or freeze-drying process, the water sample is frozen and the water is removed by sublimation under vacuum. The more-volatile organic constituents are lost in this process. Concentration factors of several thousand can be achieved and are limited by recovery of the organics from the residue, which is composed largely of inorganic salts. Commercial lyophilizers are capable of processing many liters of water per day. This process has been used to prepare concentrates for chemical analysis and biological testing. A major disadvantage is the difficulty in recovering the organic material from the inorganic precipitates. (Jolley et al., 1978; Cumming et al., 1978).

VACUUM DISTILLATION

In the vacuum distillation or evaporation process, the water sample is boiled at reduced pressure and at ambient or near-ambient temperature. This process has been used to concentrate water samples for chemical analysis and for determination of biological activity (Jolley et al., 1975; Johnston and Verdeyen, in press). This process has essentially the same disadvantages as th lyophilization process; however, vacuum distillation is usually more labor intensive than lyophilization. Laboratory-scale equipment is limited to sample volumes of several liters per day.

REVERSE OSMOSIS

In the reverse-osmosis process, water is forced through a membrane by application of pressure greater than the osmotic pressure across the membrane, thereby enriching the water sample in constituents that cannot pass through the membrane. Commercial units capable of handling many liters per day are available. The membrane is generally either cellulose acetate or nylon. A disadvantage of reverse osmosis is that the membranes may either adsorb constituents or release contaminants into the sample. Cellulose acetate membranes for reverse osmosis are commonly rated to reject 90 to 97% of the inorganic ions and organic constituents with molecular weights >200. This process has been used to prepare water samples for chemical analyses and for determination of biological activity (Kopfler, 1980a; Tardiff et al., 1978; Kopfler et al., 1975; Kopfler et al., 1977). Approximately 30 to 40% of organics are recovered from tap water when solvent extraction and dialysis are used in combination with reverse osmosis (Kopfler et al., 1975). Kopfler et al. (1977) indicate that cellulose acetate membranes reject ∼85% of the total organic carbon from the Cincinnati, Ohio, drinking water.

ULTRAFILTRATION

In the ultrafiltration process, the water sample is filtered under pressure through a membrane filter that will pass molecular constituents below a certain size (e.g., 1000 mol wt) and retain those above that size. This technique has been used to concentrate higher-molecular-weight constituents for chemical analysis (Milanovich et al., 1975; McCahill et al., 1980). An obvious disadvantage is the loss of lower-molecular-weight constituents. Commercial units capable of filtering liter quantities per day are available. Milanovich et al. (1975) indicate good recoveries of organic constituents by both ultrafiltration and lyophilization, but ultrafiltration is superior for recovery of humic materials. Pope (1980) indicates that a high concentration of salt occurred in the retentates from a series of experiments in which vacuum distillation was used for preconcentration.

ISOLATION TECHNIQUES

SOLVENT EXTRACTION

Solvent extraction is the extraction of water with immiscible organic solvents. This has long been a unit process of considerable significance to the chemical industry. According to Kopfler (1980a), direct liquid-liquid extraction is suitable for recovery of organics from liter volumes of water, but continuous extractors are recommended for large volumes. Continuous liquid-liquid extractors are available. Suffet et al. (1976) report the use of continuous liquid-liquid extractors to remove organics from drinking water supplies.

Kopfler (1980a) indicates that impurities present in solvents can be concentrated along with sample constituents; for example, cyclohexene, which is present in the best grades of methylene chloride solvent. Kopfler also cites the possibility that peroxide contaminants in ether may react with sample components.

A major disadvantage of solvent extraction is specificity. Organic solvents and extraction parameters (e.g., pH, ionic strength, and temperature) must be tailored to accommodate the chemistry of the material to be extracted.

ACTIVATED CARBON

In this process, the water sample is passed through a column of activated carbon and the adsorbed organic constituents are subsequently eluted with a suitable solvent. The activated carbon adsorption process has been developed extensively over several decades (Braus et al., 1951; Rosen, 1976). It has been the principal choice for chemical analysis and is used as a standard metho for water analysis (Standard Methods, 1976). Activated carbon samplers have been developed which are capable of processing many thousands of gallons (Middleton et al., 1962). A major disadvantage of the activated carbon process is that recovery of the adsorbed organics is not complete. The usual recovery process is to air dry the carbon and use a prolonged Soxhlet extraction with chloroform and ethanol (Kopfler, 1980a). Supercritical liquid carbon dioxide is being evaluated as a solvent for organics adsorbed on activated carbon (Modell et al., 1978).

XAD RESIN

The adsorption on XAD resins of organic components in aqueous solutions has been studied extensively. Two types of XAD resins (produced by Rohm and Haas) are available: a series of resins that are essentially styrene-divinylbenzene copolymers, and an acrylic ester polymer (Kopfler, 1980a; Dressler, 1979; Junk et al., 1974). These resins have macroreticular characteristics and high sorptive capacity (Junk et al., 1974). A disadvantage is that the resins must be exhaustively extracted prior to use to remove contaminants. For example, XAD-2 resins are prepared for chromatographic use by serial extraction of the resin with methanol, diethyl ether,and acetonitrile in a Soxhlet extractor (Junk et al., 1974). Clean resins must be stored under methanol and, prior to use, evaluated to ensure that resin contaminants are minimal during chromatography

XAD resins have been used to isolate organic constituents for chemical analysis and determination of biological activity. The styrene-divinyl benzene series (e.g., XAD-2) has a high affinity for nonpolar (hydrophobic) constituents (Junk et al., 1974). However, these resins are limited in retention capacity for polar constituents. The macroreticular, nonionic, acrylic ester polymer (e.g., XAD-8) is much more efficient than XAD-2 in the recovery of polar (hydrophilic) components such as humic substances (Thurman et al., 1978).

Adsorption optimization generally requires pH adjustment and control of flow rates. Malcolm et al. (1977, 1980) estimate that about 50% of the total organic carbon of the average water sample can be concentrated on an XAD-8 resin column.

Adsorbed organic constituents are recovered by elution with organic solvents or, in the case of ionizable substances, by elution with aqueous acidic or basic solutions. In the latter case, although a more-concentrated aqueous solution is obtained than the original water sample, further concentration may be necessary for biological testing. A variety of organic solvents are used for eluting adsorbed neutral organic constituents (e.g., diethyl ether, methanol, acetone, and methylene chloride). As in the case of activated carbon, all adsorbed organic substances may not be recoverable from the resin. For example, Aiken et al. (1979) indicate that about 20% of the humic substances bind irreversibly to XAD-2 resin after adsorption at pH 2 and cannot be eluted with alkali or organic solvents.

PRECIPITATION

Specific chemicals or types of substances may be precipitated from aqueous solutions and separated by centrifugation or filtration. For example, humic acids are operationally defined as the base-soluble, acid- and alcohol-insoluble organic fraction in soil or aqueous samples (Martin and Pierce, 1971; Schnitzer and Khan, 1978). Humic materials may be precipitated from aqueous solutions by acidification with glacial acetic acid and the addition of isoamyl alcohol (Martin and Pierce, 1971). This method was applied to freshwater and seawater samples but recoveries were not given. The principal disadvantage of this concentration procedure is lack of specificity.

CENTRIFUGATION

Centrifugation is a useful procedure for separating macromolecular material but has limited utility for soluble molecular constituents. Humic substances have been separated by analytical ultracentrifugation by Amburgey (1967). This method has not been developed sufficiently to accommodate large-sample volumes and is currently useful only for analytical purposes.

GAS STRIPPING

Several analytical procedures are based on using an inert purge gas to sweep over or sparge through aqueous samples, thereby transporting volatile constituents from the liquid phase into the gas phase and permitting them to be subsequently trapped cryogenically or on adsorbants. This forms the basis for several analytical procedures; for example, closed-loop stripping procedure (Grob and Grob, 1974; Grob and Zürcher, 1976), the purge-and-trap procedure (Bellar and Lichtenberg, 1974), and head-space analysis (Rook, 1974). This method is currently limited to analytical-size sample volumes.

COMBINATION PROCEDURES

Several concentration procedures have been developed specifically to obtain sufficient organic material for biological testing in addition to chemical analysis. These procedures combine several techniques to achieve as high a recovery of organics as possible.

Kopfler and his research group use reverse osmosis for large-volume samples in combination with Donnan dialysis, solvent extraction, and adsorption on XAD-2 resin to recover an estimated 35 to 40% of the organic substances from water samples (Kopfler,1980a; Kopfler et al., 1977). This method has been used extensively to prepare samples for biological testing (Tabor et al., 1980; Loper et al.,1978; Loper, 1980).

Johnston and Verdeyen have developed a method that involves the use of silica gel, cation exchange resin, and anion exchange resin followed by vaccum distillation. Materials are recovered from the resins by elution with a triethylammonium carbonate buffer followed by acetone. Recovery of spiked organic mutagens from river water samples by this parfait/distillation method was found to depend strongly on the stability of the compound in the environmental water (Johnston and Verdeyen, in press).

Baird and coworkers have developed a procedure capable of processing continuously large volumes of water. This method uses sequential ion exchange resin columns and subsequent recovery of the organic material by elution. The resins, in order of use, are Biorad MP-1 (macroporous anion exchange resin), Biorad MP-50 (macroporous cation exchange resin), XAD-2, and XAD-7 (macroreticular nonionic resins). The resins were extracted with either H_2SO_4, KOH, acetonitrile, or a combination of these. Organic carbon removals from secondar and tertiary effluents were 70 to 90% (Baird et al., 1980a; Garrison et al., 1980).

Carbridenc and Sdika (1979) have developed an apparatus to sequentially extract $\leq$1000 L of water with 100 L of chloroform under an inert gas at pH 7, 2, and 10, followed by XAD-2 and activated carbon adsorption. Total recovery of standards from this system was calculated to be 88 wt %. Extracts of drinking water have been prepared and tested for biological activity.

CRITICAL AREAS

Kopfler (1980a) indicates there are several areas of concern in preparing representative concentrates for biological testing. For example, changes may occur in organic residues during storage of concentrates between preparation and biological testing or chemical analysis. In addition, humic materials may bind lower-molecular-weight organic substances; consequently, their recovery is necessary to ensure recovery of the bound constituents.

SUMMARY OF CONCENTRATION METHODS

Because of the large variety of chemical compounds present either naturally or as industrial contaminants in water samples, no single concentration method currently available is adequate for concentrating all organics in the water sample. Consequently, in an attempt to concentrate or isolate as much of the organic matter as possible, most researchers have combined several methods that may become quite complex and technically difficult to achieve. Table 1, which summarizes most of the current practical methods for achieving concentration of organics from water samples, indicates the utility of each method along with major advantages and disadvantages. Several of the methods have been used to prepare concentrates for biological testing. Table 2 presents selected examples of these methods along with the principal biological test used and the reference citation. Although the concentration method may be limited with respect to concentrating all organic matter, significant positive results were achieved in most of the studies. There is thus a question as to whether a single concentration method or a combination of methods can be developed to achieve concentration of all organic matter in a water sample or whether this is necessary. That is, it may be profoundly more simple and economical to use several different concentration methods to concentrate and isolate organic matter for biological testing. This, however, raises the specter of omitting a significantly toxic substance because the concentration methods selected were not adequate for that specific compound.

RECOMMENDED METHODOLOGY FOR ORGANIC CONSTITUENTS

Selection of the concentration method must be based on the biological test to be conducted. For example, a long-term feeding study of mice could require organic material from many thousands of liters of water. In addition, the concentration method must currently be chosen on the basis of the chemical

Table 1. Summary of methods for concentrating and isolating organic constituents from water samples

Method	Type organic concentrated	Advantages	Disadvantages
Concentration technique			
Freeze concentration	Polar and nonpolar	Low temperature	Liter volumes, limited concentration, salt concentration
Lyophilization	Nonvolatile	Low temperature, high concentration, low contamination	1-100 liter volumes, salt concentration
Vacuum distillation	Nonvolatile	Ambient or near ambient temperature, high concentration, low contamination	1-100 liter volumes, salt concentration
Reverse osmosis	Molecular weight >200	Ambient temperature, >100 liter volumes	Salt concentration, contamination
Ultrafiltration	Molecular weight >1000	Ambient temperature	Salt concentration, liter volumes
Isolation technique			
Solvent extraction	Nonpolar, volatile	Ambient temperature, large volumes, low salt concentration	Solvent contamination, specificity, concentrate storage
Activated carbon	Nonpolar, volatile, nonvolatile	Ambient temperature, >1000 liter volumes	Limited recovery of adsorbed organics, concentrate storage, artifacts

Table 1. (Contd.)

Method	Type organic concentrated	Advantages	Disadvantages
Isolation technique (contd.)			
Ion exchange	Polar, nonpolar	Large volumes, organic recovery 70-90%	Resin preparation and elution
XAD resin	Nonpolar to polar, volatile, nonvolatile	Convenient, ambient temperature, large volumes	Contamination, limited recovery of adsorbed organics, resin preparation
Precipitation	Humic materials, specific chemicals		Specificity
Centrifugation	Macromolecules		Specificity, i.e., large molecules, low volumes
Gas stripping	Volatile	Small samples	Low volumes

Table 2. Selected examples of methods used to prepare organic concentrates for biological testing

Water sample	Concentration method	Reference	Biological testing
Drinking water	Reverse osmosis	Neal, 1980	Initiation-promotion study (SENCAR mice)
Drinking water	XAD	Neal, 1980	Initiation-promotion study (SENCAR mice)
Drinking water	Reverse osmosis	Neal, 1980	Ames test
Drinking water	Reverse osmosis	Loper, 1980	BALB/3T3 fibroblasts
Drinking water	XAD	Cheh et al., 1980	Ames test
Paper plant effluents	XAD	Douglas et al., 1980	Ames test
Drinking water	Solvent extraction (combination)	Hemon et al., 1978	Cytotoxicity, promotion
Drinking water	Solvent extraction	Cabridenc and Sdika, 1979	Ames test, cytotoxicity, promotion
Wastewater effluents	Lyophilization and vacuum distillation	Cumming et al., 1979	Ames test
Wastewater effluents	Ion exchange (combination)	Baird et al., 1980	Ames test
Wastewater effluents	Ion exchange and distillation	Johnston and Verdeyen, in press	Ames test
Drinking water	Reverse osmosis	Tardiff et al., 1978 Kopfler et al., 1977	Ames test
Drinking water	Reverse osmosis	Tabor et al., 1980 Loper et al., 1978	Ames test

and physical properties of the organic constituents to be tested.

VOLATILE CONSTITUENTS

Because of technical difficulties in the biological testing of highly volatile constituents, such constituents have generally been tested as specific chemical compounds rather than as concentrates. Moderately volatile and less-volatile constituents may be tested as concentrates. Concentration of volatile constituents by solvent extraction now seems to be the most amenable to the preparation of concentrates for biological testing.

NONVOLATILE CONSTITUENTS

Reverse osmosis, in combination with other methods as used by Kopfler et al., (1977) is apparently the most useful method for preparation of large quantities of organic concentrates. However, if thousands of liters per day must be processed, the method of concentrate preparation must be simpler. Thus, XAD adsorptio or activated carbon adsorption may be preferred.

SPECIFIC CLASSES OF COMPOUNDS

If specific classes of compounds or specific chemical compounds are to be biologically tested, the specific concentration method may be tailored to isolate these compounds: for example, the separation of humic materials from water samples by alkaline extraction and acid precipitation.

RECOMMENDATION FOR METHODOLOGY DEVELOPMENT

The usefulness of biological tests of organic concentrates to estimate the hazards associated with water is dependent on the degree to which the concentrate represents the actual organic materials present in the water; that is, to estimate the total hazard, the organic concentrate must be representative of all the organic substances present in the water. Thus efforts must be continued to develop simple but efficient methods for concentrating all the organic materials actually present in water samples. However, this may not be technically possible.

It is recommended that methods to evaluate and compare different concentration techniques be developed and applied. This will require increased emphasis on chemical analysis to identify much of the organic material in the concentrates. Measurements of general parameters, such as total organic carbon, cannot be used to reliably compare concentration techniques. Kopfler (1980b) proposed that all techniques be compared by determining the recovery of a series of compounds of various solubilities selected to include a range of chemical classes, functional groups, and molecular weights. He recommends the inclusion of aquatic humic substances and this same material after reaction with chlorine. Kopfler also recommends standardization of techniques to minimize contaminants so that the contaminants remain at constant levels each time the concentration method is used. Contaminants unique to the concentration process must be identified and quantified to determine the effect of the contaminants on the biological test and to permit proper evaluation of the biological test of the concentrate itself. Possible artifact production of the concentration methods must be evaluated; for example, it is suspected that peroxide in ether used to elute adsorption columns may create artifacts. The stability of concentrates during storage must also be evaluated.

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APPENDIX TO ISSUE PAPER

"CHEMISTRY"

Chairman: I.H. Suffet, Drexel University, Philadelphia, PA
Reporter: W.J. Cooper, Florida International University, Miami, FL

INORGANIC CHEMICALS IN REUSE SYSTEMS

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INTRODUCTION

In attempting to develop criteria and standards for inorganic chemical constituents in the reuse of renovated wastewater for potable purposes, it is not sufficient to consider only the "simple" question as to whether specific chemicals will exceed health related maximum constituent limits (MCL's). On the contrary, a broad data base must be developed in order to satisfy the understandable concern that the renovated wastewater does not result in hazards to human health qualitatively and quantitatively greater than those in our long history of use of "natural" (and even anthropogenically contaminated) waters as sources for our domestic supplies.

To satisfy this concern we must establish exhaustive data on the nature and concentrations of inorganic chemicals in the (domestic) wastewaters to be renovated, including their time variabilities; the efficacy and its variability in the treatment of these constituents; and ultimately their concentrations that will occur in the renovated water delivered to the consumer for potable use. The processes themselves are of importance in that they in effect are replacing what would otherwise be natural ones of dilution and other natural effects (e.g., precipitation and sorption). The critical question then arises, how can we put this complex set of information into a framework of decision-making for developing a criterion and monitoring strategy for the inorganic chemicals to protect the public health in potable wastewater reuse? The aim of this paper is to provide some views and background information to assist in this goal. It should be noted, however, that it will not focus either on the need for or the adequacy of specific health criteria; nor on toxicity testing of renovated wastewaters. It will be assumed that these will be dealt with elsewhere.

SOURCE WATER QUALITY AND ITS VARIABILITY

In assessing the potential safety of a municipal wastewater to be renovated and reused for a potable supply it is necessary to have information about the possible sources of chemicals in the first water use (domestic and possible industrial inputs); the impacts of conventional (usually secondary) wastewater treatment; and the typical concentrations of the inorganic chemicals and their variability in the secondary effluent to be used as a source for the renovation or advanced wastewater treatment system. The possible build-up of macro inorganics, such as sulfate, calcium, and magnesium, although they may not have adverse health implications, may be esthetically undesirable. In addition, many trace inorganics, such as nitrate, mercury, and lead, clearly can adversely affect health.

Domestic water use results in the addition of a variety of inorganic constituents as shown in Table 1 . This table does not, however, convey information about the wide variety of trace inorganic chemicals (typically those at concentrations less than 1 mg/l) that may be added as a result of domestic and industrial uses of a public water supply. Thus, in assessing a municipal wastewater for possible reuse, it is imperative to undertake an analysis of not only the domestic use impacts, but also the industrial inputs to the system, and if it includes stormwater, the possible runoff constituents as well. Following such analyses it may be necessary to strictly limit industrial inputs to the wastewater system, or perhaps only reuse such wastewaters that receive very few or no substantial industrial effluents.

TABLE 1 From Chang and Page, Ref.1

Incremental increase of mineral constituents due to domestic water use.

Constituent	Range of incremental increase
	- - - mg/liter - - -
Boron	0.1 - 0.4
Sodium	40 - 70
Potassium	7 - 15
Magnesium	4 - 10
Calcium	6 - 16
Phosphate ($PO_4^{\equiv}$)	20 - 40
Sulfate ($SO_4^{=}$)	15 - 30
Chloride (Cl^-)	20 - 50
Total dissolved solids	100 - 300
Alkalinity	100 - 150
Total nitrogen	20 - 40

It should be noted that there can be some transformations of inorganic chemicals in the secondary treatment systems (such as ammonia to nitrate), as well as reductions (e.g., due to precipitation), and additions (such as contaminants from lime). An evaluation of the persistence of chemical pollutants in wastewater reuse has been presented by England and Reimers (2). As part of that study they summarized studies of the residual concentrations and removals of several trace and other chemicals in secondary sewage treatment, as shown in Table 2 . They noted that there was a "wide range of demonstrated removal efficiencies which appear largely unpredictable." It is, therefore, apparent that even an exhaustive analysis of the trace inorganic content of a raw sewage cannot be used as a basis for estimating their concentrations in a specific treated secondary effluent. Actuales of studies of removal of the specific constituents in the system of interestsary are necessary as well in order to assess its possible use for wastewater renovation.

A variety of studies indicate that secondary or biologically treated municipal wastewater can indeed have a wide range of trace element concentrations, as shown in Table 3 . For many of the constituents the range of concentrations is as high as a factor of 100, and these data presumably reflect both variation among and within given secondary effluents. It is thus unlikely that one can define a "typical" municipal secondary effluent with respect to inorganic constituent concentrations. It will be necessary then to carefully evaluate the concentrations of such constituents in order to determine if a specific system is a good candidate for reuse. In this regard the variability, as well as the mean concentrations of inorganic chemicals, in the secondary effluent is also of concern. Table 4 presents such data for the secondary effluent used as the source water for Water-

TABLE 2 From Englande and Reimers, Ref. 2

Removal of Selected Contaminants by Biological Treatment

	Ranges of Removals as Reported by Cohen	LA Sanitary District Projected Removals		Activated Sludge Removal Dallas		EPA Study Removal	
			Residual Metal		Residual Parameter		Residual Parameter
	Per Cent	Per Cent	(µg/1)	Per Cent	Concentration	Per Cent	Concentrat
TOC	-	-	-	70.7	12 mg/1	60.0	25 mg
COD	-	-	-	80.7	50 mg/1	73.0	110 mg
NH_3-N	-	-	-	67.3	5 mg/1	42.0	14 mg
TKN	-	-	-	61.3	9 mg/1	34.0	18 mg
NO_3 & NO_3-N	-	-	-	Inc.**	5.1 mg/1	-	-
Phenol	-	-	-	-	-	45.0	175 µg
Ag	-	69	5.3	Inc.**	2.6 µg/1	-	-
As	-	48	5.2	18.7	17.0 µg/1	-	-
B	-	-	-	Inc.**	300 µg/1	-	-
Ba	-	-	-	33.3	120 µg/1	-	-
Cd	20-45	73	5.7	58.3	5 µg/1	18	30 µg
Cr	40-80	77	240*	64.9	27 µg/1	42	218 µg
Cu	0-70	76	-	79.4	29 µg/1	56	113 µg
Fe	-	-	-	9.2	590 µg/1	57	1827 µg
Hg	20-75	84	0.19	44.8	0.16 µg/1	35	3.5 µg
Mn	-	-	-	42.3	41 µg/1	35	140 µg
Ni	-	-	-	-	-	21	182 µg
Pb	50-90	80	58	52.8	34 µg/1	38	92 µg
Se	-	-	-	34.1	2.9 µg/1	-	-
Zn	35-80	77	497*	44.2	63 µg/1	52	277 µg

*Source controls needed to meet ocean outfall criteria

**Inc. - Increase

TABLE 3 From Chang and Page, Ref. 1

Concentration of trace elements in treated wastewater.

	Wastewater effluent		Water quality criteria		
			Public water supply	Irrigation water	
Element	Range	Median		Continuous use[†]	Short-term use[§]
	- - - - - - - - - - - - -		mg/liter	- - - - - - - - - - - - -	
As	<0.005-0.023	<0.005	0.1	0.1	2.0
B	0.3 -2.5	0.7	---	0.75	2.0
Cd	<0.005-0.22	<0.005	0.01	0.01	0.05
Cr	<0.001-0.1	0.001	0.05	0.1	1.0
Cu	0.006-0.053	0.018	1.0	0.2	5.0
Pb	0.003-0.35	0.008	0.05	5.0	10.0
Mo	0.001-0.018	0.007	---	0.01	0.05
Hg	<0.0002-0.001	0.0002	0.002	---	---
Ni	0.003-0.60	0.004	---	0.20	2.0
Se	---	---	---	0.02	0.02
Zn	0.004-0.35	0.04	0.05	2.0	10.0

[†] For waters used continuously on all soils.

[§] For use up to 20 years on fine-textured soils of pH 6.0 to 8.5.

TABLE 4 From McCarty et al.,Ref. 3

COMPARISON BETWEEN NATIONAL INTERIM PRIMARY DRINKING WATER (NIPDW) REGULATIONS AND INFLUENT WATER QUALITY#

		Influent Water (Q1)			
		Second Period		Third Period	
Contaminant	NIPDW MCL	Geometric Mean	98% of Time Less Than	Geometric Mean	98% of Time Less Than
Arsenic, mg/l	0.05	<0.005	<0.005**	<0.005	<0.005**
Barium, mg/l	1.0	0.08	0.14	0.03	0.06
Cadmium, mg/l	0.01	0.026	0.07	0.033	0.15
Chromium, mg/l	0.05	0.14	0.31	0.048	0.11
Lead, mg/l	0.05	0.02	0.051	0.007	0.017
Mercury, mg/l	0.002	0.0016	0.025	<0.001	?
Nitrate (as N), mg/l	10	0.23	1.2	2.8	49
Selenium, mg/l	0.01	<0.0025	<0.0025**	<0.0025	?
Silver, mg/l	0.05	0.003	0.007	0.001	0.006
Fluoride, mg/l	1.4*	1.4	2.0	1.3	1.9
Coliforms, MPN/100ml	1	89	38,000	1.6	195
Endrin, µg/l	0.2	<0.01	<0.01	<0.01	<0.01
Lindane, µg/l	4	0.2	0.9	0.14	0.22
Toxaphene, µg/l	5	<0.01	<0.01	<0.01	<0.01
2,4-D, µg/l	100	<0.01	<0.01	<0.01	<0.01
2,4,5-TP, µg/l	10	<0.01	<0.01	<0.01	<0.01
Methoxychlor, µg/l	100	<0.1	<0.1	<0.01	<0.01
Turbidity, TU	1	42	79	7	54

#Underlined values represent those exceeding MCL

* Temperature > 26.3 C°

** Based on less than 1 in 20 samples analyzed

Factory 21 (3), the purpose of which is to reclaim biologically treated municipal wastewater to supply the injector water for a seawater-barrier system in Orange County, California. The constituents listed in this table are those which are specified in the E.P.A. National Interim Primary Drinking Water Regulations (NIPDWR). Two types of time variabilities can be seen. First, the geometric mean concentrations for many of the inorganic constituents vary substantially between the two time periods studied. For example, the two mean values for lead are 0.02 and 0.007 mg/l. Another important parameter shown in this table is the highest concentration which is not exceeded 98 percent of the time. For some of the constituents this concentration is much larger than that of the geometric mean in the same time period. Thus, for mercury in the second period, these two concentrations are 0.025 and 0.0016 mg/l, respectively, a factor of about 15. From such data it is clear that the time variability of a secondary sewage effluent should be evaluated in assessing it as a source water for a reuse system; this can have a substantial impact on the quality of the renovated water product.

RENOVATED WASTEWATER QUALITY AND ITS VARIABILITY

Having recognized the concentrations of inorganics that may be encountered, as well as their variabilities in the secondary sewage effluents that may be utilized as the source water for a renovation-reuse system, the next step in the evaluation sequence is an assessment of the efficiency and reliability of the renovation processes. Such an assessment must clearly focus not only on the likely average removals, but also on the time variabilities that may be encountered. For inorganics that are of principal concern from the point of view of chronic adverse impacts on human health, the average exposure is of greatest interest. However, in many cases the same chemical, such as cadmium, can also have an acute impact, although the tolerable concentration for this may be higher. In such instances the high concentration excursions from the mean may be acceptable, but only at specified levels and for limited periods of time.

The removal efficiencies of advanced wastewater treatment and renovation processes can be highly variable, both with respect to the process and the inorganic constituent. Englande and Reimer have reviewed both the technical literature and the results from specific advanced wastewater treatment systems (2). A summary of their findings for several trace elements and other constituents is shown in Table 5 . This indicates that not only does the specific unit process affect various elements differently, but also that other water quality variables and influent concentrations play a role as well. Clearly there is no single process, at least among those summarized, that readily

TABLE 5 From Englande and Reimers, Ref. 2

Pollutant Removal by Wastewater Treatment Processes

(Noted in Per Cent Removal)

CONSTITUENT	SECONDARY TREATMENT (BIOLOGICAL)	CHEMICAL PRECIPITATION			ACTIVATED CARBON ADSORPTION	COMMENTS ON ACTIVATED CARBON	RESIDUAL LEVEL (μg/l)	GENERAL COMMENTS ON REMOVAL
		LIME	FERRIC CHLORIDE	ALUM				
Total Dissolved Solids	P	P	-	-	P	-	-	Generally increase S with treatment. Re rse Osmosis effective in removal.
Ammonia Nitrogen	VG	P	-	-	P	-	-	Bio nitrification t effective; Breakpoi Chlorination and Stripping Towers F to VG
Nitrate Nitrogen	VG	P	-	-	P to G	Depends on anaerobic bioactivity	-	Bio denitrification ost feasible
Phenol	P	P	-	-	P	Limited by driving force to about 1 mg/l	>1 μg/l	Treatment methods n effective in reducing Phenol to 1 μg/l limit
Trace Organics	G	G	-	-	G	Removal depends on specific organics	=5 mg/l TOC and COD	Chlorinated Organic may be increased with B k-point Chlorination; m-monia Stripping effective in Removing Volatile Refractory Organics
Arsenic (As)	F to F	F to G	G	-	P	Reacts with Sulfides	3 μg/l	Depends on influent level, pH, and Redo potential
Barium (Ba)	F	F to G	-	G	F to G	Due to highly soluble nature	>30 μg/l	Enhanced precipitation a Sulfate conc. increases
Boron (B)	P	P	-	-	P	-	>290 μg/l	Generally negligibl
Cadmium (Cd)	F to G	F to VG	-	F	F to VG	Old Carbon better	2 μg/l	High removals due t precipitation of Sulfic and Hydroxide forms
Chromium (Cr)	F to G	G	VG	G (Cr^{+6}) VG (Cr^{+3})	F to G (Cr^{+3}) VG (Cr^{+6})	Reduction with Bio-activity Cr^{+3} less soluble than Cr^{+6}	10 μg/l	Depends on influent vel and oxidation state
Copper (Cu)	F to G	F to G	-	G	G to VG	Enhanced Sorption better with New Carbon	70 μg/l	Influenced by Influent Concentration
Iron (Fe)	P to F	P to VG	-	-	P to G	Sulfide complexes ppt. but anaerobic bio-activity causes reduction to soluble Fe^{+2}	>40 μg/l	Depends on influent level, pH, and Redox potential
Lead (Pb)	F to G	F to G	-	VG	F to G	-	>5 μg/l	Enhanced precipitat with higher Sulfate levels
Manganese (Mn)	F	G to VG	-	P	P	Bioactivity on the Carbon reduces Mn^{+4} to Mn^{+2} and release	5 μg/l	Depends on pH and Redox potential
Mercury (Hg)	F to G	F to G	VG	G	F to G	Variability due to biological activity	5 μg/l	Removal is a functic of pH, initial conc., and degree of complexation
Selenium (Se)	F	P to G	G	F	P to G	Variability due to highly soluble characteristics	2 μg/l	Depends on influent concentration
Silver (Ag)	F to G	F to VG	VG	VG	F to G	High affinity for Sulfhydryl groups	2 μg/l	Depends on influent level
Zinc (Zn)	F to G	P to F	-	P	F to G	Zinc Sulfide ppt.	>60 μg/l	Depends on influent Sulfate levels

Poor (P) - <30% Fair (F) - 30-60% Good (G) - 60-90% Very Good (VG) - >90%

stands out as the clear choice for "general" trace element removal. Even reverse osmosis (R.O.), which would be expected to be highly efficient in removing inorganic constituents, in one study by Hrubec et al. (4) was found to be much less effective for most trace elements than for macro inorganics. Their results are shown in Table 6 .

Culp has also summarized contaminant removal capabilities and reliability data from a large number of operating and pilot advanced waste treatment facilities (5), and this is shown in Table 7 for an "average" process train. The average percent removal varies considerably among the trace elements, from a low of 7 percent for selenium to a high of 100 percent for chromium. These are reflected in the average effluent concentrations shown in the last column. However, it is also important to note that for most of the trace elements 90 percent of the time the maximum percent removals were substantially less than the average. Thus, for example, with cadmium one can calculate that the average influent concentration is 0.01 mg/l. Since for 90 percent of the time the maximum removal is 87 percent, for 10 percent of the time the effluent concentration would be expected to be greater than 0.0013 mg/l. This is 6.5 times the average effluent concentration of 0.0002 mg/l. Although it is risky to use such data for an "average" process to predict time excursions from average expected concentrations, the concept is important to apply in evaluating possible human exposures to constituents in renovated waters.

This time variability in treatment efficiency for trace inorganics has also been considered in some detail in the Water Factory 21 study by McCarty et al. (3), both in terms of variability in influent concentration and removal efficiency. This is shown for that study in Figure 1 for eight heavy metals. These are plotted as log normal distributions, which are often

TABLE 6 From Hrubec et al., Ref. 4

Removal of inorganic constituents during the Reverse-Osmosis System

Parameter *	Secondary effluent	Feed R.O.	Effluent R.O.	Effluent marble filter
Conductivity	1220 µS/cm	1220 µS/cm	50 µS/cm	215 µS/cm
Cl^-	-	161	12	-
SO_4^{2-}	-	107	2	-
F^-	0.6	0.5	0.07	0.05
HCO_3^-	365	357	15	128
pH	7.5	7.5	5.2	7.9
Ca^{2+}	102	104	3	43
Mg^{2+}	15	14	1	1
Na^+	110	110	3.5	3.5
K^+	17	16	1	1
NH_4^+	-	14.5	1.4	0.18
NO_2^-	1.0	1.0	0.01	0.01
NO_3^-	30	30	3.0	7.3
PO_4^{3-}-ortho	15	11	0.07	0.04
SiO_2	25	21	1	5

* units in mg/l unless otherwise stated

Removal of organic compounds and trace elements during the Reverse-Osmosis System

Parameter *	Secondary effluent	Feed R.O.	Effluent R.O.	Effluent marble filter
COD	47 mg/l	32 mg/l	3 mg/l	2 mg/l
DOC	14 mg/l	11 mg/l	1.7 mg/l	1.3 mg/l
As	5	4	0.5	0.5
Cd	1.2	0.4	0.1	0.1
Cr	2.4	1.8	0.5	0.5
Cu	3.0	1.8	0.5	0.5
Hg	0.1	0.1	0.1	0.1
Mo	7	7	2	2
Ni	6.3	6.8	1	1
Pb	9.4	3.3	0.5	0.5
Se	2	2	2	2
Zn	80	40	10	10

* units in µg/l unless otherwise stated

TABLE 7 From Culp, Ref. 5

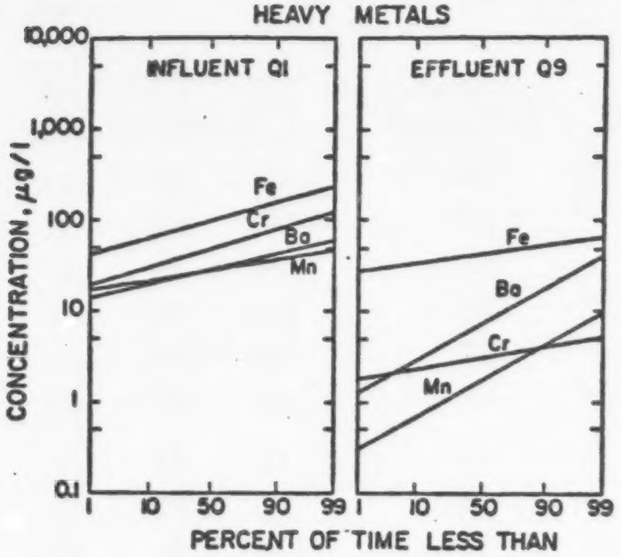
Average Process Train Performance

(Act. sludge, hi-lime, recarb., flow equal., ion exch., bk.-pt. Cl_2, GAC adsorption, R.O., ozonation, and chlorination)

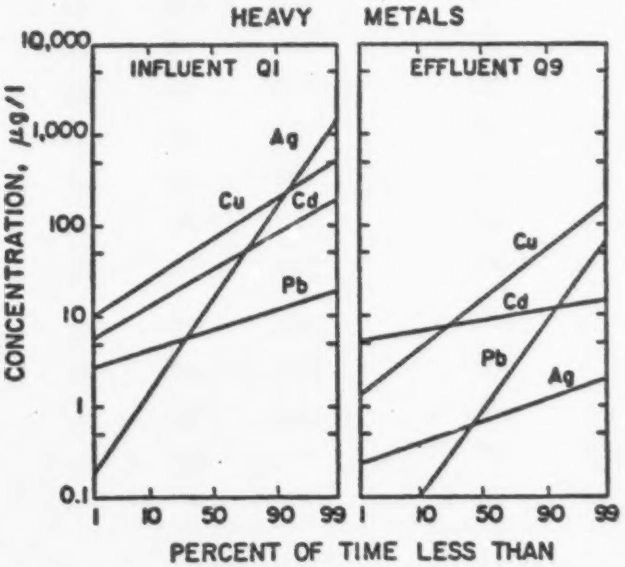
		Average Reliability			
Constituent	Average Removal, %	10%	50%+	90%	Average Effluent Concentration, mg/1
		(% Removals)			
BOD	100	100	100	89	0
COD	100	100	100	97	< 1
TSS	100	100	99	87	0
NH_3-N	100	100	91	68	0
Phosphorus	100	100	100	99	0
Oil & Grease	100	100	100	90	0
Arsenic	61	93	63	0	.003
Barium	79	95	79	52	.092
Cadmium	98	100	98	87	.0002
Chromium	100	100	98	84	0
Copper	98	100	99	98	.002
Iron	99	100	100	94	.023
Lead	99	100	98	78	.001
Manganese	98	100	98	86	.002
Mercury	23	31	18	0	.028
Selenium	7	26	12	0	.006
Silver	82	100	99	80	.004
Zinc	98	100	95	58	.008
TOC	100	100	98	83	< 1
Turbidity	100	100	100	95	< 0.1*
Color	93	100	94	56	5**
Foaming Agents	92	-	84	-	.17
TDS	95	-	-	-	129

*TU
** P-C Units
+ Median removal
SYMBOLS: x - data inconclusive
- - insufficient data

FIGURE 1 From McCarty et al., Ref. 3



Distribution of heavy metal concentrations in the influent and effluent during third period.



Distribution of heavy metal concentrations in the influent and effluent during third period.

encountered and were found to be a useful way of evaluating performance of the treatment system. However, it is important to note that confidence limits or uncertainties are associated with the log normal distribution lines, and this is discussed in that report. Where the distributions for the influent and effluent concentrations are parallel, this is consistent with the fractional removal being independent of concentration. However, for the metals shown in Figure 1 the lines are typically parallel. Also, where the effluent slopes are large, such as for lead and copper, the expected time excursions from the mean are also large. The results for these elements and a few others are shown in Table 8, where not only are the average percent removals presented, but also the 95 percent confidence interval for the average. This can be quite large for some elements, such as copper, lead, and silver. To use this in a conservative way to predict average maximum concentrations in the effluent, one would have to use the minimum average removal percentage. Thus for cadmium one should use the 47 percent average removal, rather than 84 percent (these two limits representing the extremes of the 95 percent confidence band).

The use of these concepts and the distributions associated therewith were considered in the Water Factory 21 report in terms of the reliability in meeting water quality requirements (3). The approach was to use the log normal distributions of various constituents in the injection water (in the period of interest, a blended mixture primarily of advanced wastewater and reverse osmosis effluents, with some deep well water mixed in). As shown in Table 9 , for several constituents the California state-specified maximum constituent limits (MCL's) were compared to the distributions and predictions thereby made as to the percent of time the MCL's would be exceeded.

TABLE 8 From McCarty et al., Ref. 3

SUMMARY OF HEAVY METAL CONCENTRATIONS AND REMOVALS BY AWT DURING THIRD PERIOD

	Geom. Mean Conc., μg/l		Percent Removal	
Heavy Metal	Infl. Q1	Efflu. Q8	Average	95% Conf. Inter. for Avg.
Ag	1.2	0.7	42	-24 to 73
Ba	30	7.4	75	41 to 90
Cd	33	9.5	71	47 to 84
Cr	48	3.1	94	90 to 96
Cu	72	16	78	16 to 94
Fe	98	42	57	40 to 70
Hg	<1	<1	-	-
Mn	29	1.7	94	86 to 97
Pb	7.1	1.0	86	-164 to 99
Se	<5	<5	-	-
Zn	127	<100	>21	-
As	<5	<5	-	-

TABLE 9 From McCarty et al., Ref. 3

COMPARISON BETWEEN STATE SPECIFIED MCL FOR INJECTION WATER AND ACTUAL MEASURED CONCENTRATIONS DURING PERIOD THREE; MARCH 1978 THROUGH DECEMBER 1978

		Injection Water (Q10)		
Contaminant	State Specified MCL	Geometric Mean Conc.	Predicted Percent of Time MCL Exceeded*	Number of Times MCL Exceeded**
Electrical Conductivity	900 μS/cm	500 μS/cm	12	0/306
Sodium	110 mg/l	70 mg/l	21	6/31
Hardness ($CaCO_3$)	220 mg/l	64 mg/l	11	1/31
Sulfate	125 mg/l	43 mg/l	23	3/29
Chloride	120 mg/l	69 gm/l	20	5/31
Ammonium	4 mg/l	0.3 mg/l	7	0/183
Total Nitrogen	10 mg/l	0.7 mg/l	3	0/183
Fluoride	0.8 mg/l	0.57 mg/l	18	1/31
Boron	0.5 mg/l	0.38 mg/l	17	1/39
Chromium	0.05 mg/l	0.0016 mg/l	0.1	0/40
Cadmium	0.01 mg/l	0.001 mg/l	10	1/40
Selenium	0.01 mg/l	<0.005 mg/l	—	0/34
Copper	1.0 mg/l	0.012 mg/l	10^{-3}	0/39
Lead	0.05 mg/l	0.0016 mg/l	0.1	0/40
Mercury	0.005 mg/l	<0.001 mg/l	—	0/42
Arsenic	0.05 mg/l	<0.005 mg/l	—	0/32
Iron	0.3 mg/l	0.03 mg/l	0.2	0/39
Manganese	0.05 mg/l	0.003 mg/l	0.4	1/39
Barium	1.0 mg/l	0.003 mg/l	10^{-6}	0/39
Silver	0.05 mg/l	0.001 mg/l	10^{-3}	0/40
COD #	30 mg/l	12 mg/l	0.2	0/125
MBAS	0.5 mg/l	0.04 mg/l	<0.001	0/28
Cyanide	0.2 mg/l	0.002 mg/l	<0.001	0/32
Phenol	1.0 μg/l	0.6 μg/l	32	10/30
Coliforms	2.2 /100 ml	0.01/100 ml	7	0/137##
Turbidity#	1.0 TU	0.36 TU	0.5	0/275

# MCL for COD at Q8 and for turbidity at Q6.

* Based on lognormal distribution model.

Ten samples exceeded 2.2/100 ml, but not in consecutive samples.

** Given as m/n where m = no. of times MCL exceeded out of n samples analyzed.

These were then compared to the actual numbers of samples in which the limits were found to be exceeded. It was concluded that, except for some constituents, such as sodium, sulfate, and chloride, the performance was quite reliable. This is a separate question from predictability and relates to the number of times the MCL is exceeded. However, predictability is also of importance and is expressed here in terms of the comparison between the predicted percent of time versus the actual percent in which an MCL is exceeded. In this respect sodium and sulfate are predictable constituents. In contrast fluoride and boron are not. The adherence of the distribution to the log normal form and the statistical uncertainties associated therewith are important factors in predictability.

It is clear that all of the variabilities encountered in the secondary effluents and the advanced waste treatment and renovation processes must be considered in evaluation of both predictability and reliability. Especially for trace inorganic constituents, which can exist in various states of speciati n, it is difficult to predict removals a priori for a given treatment system. Thus, as in the Water Factory 21 study, it is necessary to specifically evaluate this over an extended period of time to insure that the full range of variabilities are encountered and assessed.

BUILDUP OF CONSTITUENTS ON RECYCLE

There is often concern about the possible buildup of waste constituents in water reuse and recycling. At first it might seem that such materials would continue to accumulate during each recycle until, perhaps, they would reach solubility limits. However, it can be shown readily that a steady-state concentration, rather than an infinite build-up, will eventually be attained, as long as some fraction of the parameter in question is lost in recycle, whether through removal in treatment or the discarding of a portion of the wastewater flow. In the latter case, the flow that is not utilized would be replaced by a "fresh" source, namely makeup water.

Such possible buildups on continuous recycle have been considered by Long and Bell (6), as well as Dick and Snoeyink (7), who developed steady-state equations for the concentration factors as a function of the fraction of total flow which is recycled. This approach has been further developed by Andelman (8), who applied it to a specific wastewater reuse system. In this treatment it was assumed that constituents could be contributed to the final renovated water product from three sources: the makeup water; additions from the actual water use; and possibly from chemicals used in treatment processes. Also, the final equations which will be presented here are those for the steady-state achieved on continuous recycle. They can be modified readily to apply to a finite and small number of recycles, although in many cases steady-state is rapidly approached in any event.

From mass balance considerations one can derive the equation for the steady-state concentration in renovated water mixed with makeup water

$$C_S = \{C_M(1 - f) + C_R f + C_A fbc\}/(1 - fbc) \qquad (1)$$

with C_S being the steady-state concentration of a constituent in the renovated water mixed with makeup; C_M, that of the makeup; C_R, that in unmixed renovated water added from the renovation process; C_A, that added to the wastewater; f, the fraction of wastewater reused; b and c the fractions remaining after removal in the wastewater treatment and renovation systems, respectively. It is assumed that b and c are independent of concentration and can vary between 0 and unity, and that there are no losses or addition of water within the recycling system. It should be noted, however, that the assumption that the removal fractions are independent of concentration may indeed not be valid as discussed in the previous section.

When there are no sources of a constituent from the makeup water or renovation system, Equation 1 simplifies to

$$C_S = C_A fbc/(1 - fbc) \qquad (2)$$

In this case the critical role of the parameter f in determining C_S relative to C_A becomes apparent. For example, with $f = 0.5$ (50/50 recycle) even with no removal in the waste and renovation systems ($bc = 1$), the maximum C_S is equal to C_A, the concentration for that constituent added to the raw waste stream. However, with some reduction due to treatment ($bc < 1$), C_S will be smaller than C_A. For example, with bc equal to 0.75 for an f value of 0.5, C_S/C_A is reduced to 0.6, as compared to 1.0 in the absence of any removals in treatment. Also, since, as shown above, treatment efficacy varies considerably among inorganic constituents, so should their buildups.

Although it is useful to compare the likely steady-state concentrations of the renovated water to those introduced in the use system, C_A, another comparison of interest is between C_S and C_M, the renovated water mixture and the makeup water, respectively. For example, such a makeup water might be a normally treated public water supply and the renovated water mixed with it. In making a judgment about a reuse system, it would be of interest then for a number of constituents to evaluate the potentially recycled product in comparison with that normally used by a community. For such an approach, and again assuming that $f = 0.5$ and there is no contribution from the renovation treatment system ($C_R = 0$), using Equation 1 it can be shown that

$$C_S/C_M = (1 + bcC_A/C_M)/(2 - bc) \tag{3}$$

Thus, the ratio C_S/C_M is dependent on both C_A/C_M and bc. With bc equal to unity (no removal by treatment)

$$C_S/C_M = 1 + C_A/C_M \tag{4}$$

At the other extreme, with bc equal to zero (complete removal), $C_S/C_M = 0.5$. This latter case corresponds simply to mixing the makeup water 50/50 with uncontaminated water. In the simulated recycle system described by Andelman (8) some typical values encountered for C_A/C_M were: Ca, 0.07; Mg, 0.67; Fe, 1.31; Mn, 2.22; Na, 7.43; K, 10.1. Over this range of values, assuming no subsequent removal by treatment (bc = 1), C_S/C_M should vary from 1.07 to 11.1, according to Equation 4, and be as low as 0.5 (with bc = 0) in actual recycle.

One value of such equations is that they can be used to predict the likely steady-state concentrations that may be attained, using information developed from pilot plant and simulated recycle systems. In this context they constitute a useful tool in estimating the possible human exposures that could be encountered in such recycle systems.

MONITORING AND ASSESSING EXPOSURES

In evaluating the possible human exposures to inorganic chemicals in renovated waters to be used for potable purposes, several points should be considered. First, what constituents can be expected to be present, and at what approximate concentrations? Second, are any of these likely to be of concern; that is are they likely to be present at concentrations that could be harmful? Third, what criteria could be used to make such judgments? And finally, what measurements should be undertaken, both prior to instituting reuse, and in actual reuse? In the latter case, this would in effect constitute a strategy for monitoring. This section will focus on these questions, although not in the context of attempting to develop information on health criteria.

A wide range of inorganic constituents can and have been measured in wastewater renovation systems. One study by Pahren and Ulmer (9) reported the results of multielement analyses by proton-inducted X-ray emission (PIXE) of 70 elements (heavier than aluminum) in effluents from four advanced wastewater treatment plants. Table 10 summarizes the results for those elements detected at least once among the 14 grab samples. In addition, another 46 elements were not detected. For these elements the detection limits were typically 3 μg/l, although a few were as low as 0.3. The highest limits were for silicon, 5000; cerium 20; and praseodymium, 18 μg/l. The results in Table 10 show one constituent exceeding EPA

TABLE 10 From Pahren and Ulmer, Ref. 9

Elements Detected in Advanced Wastewater Treatment Effluents

Element	Detection Limit ppb	Percent Detected	Minimum ppb	Median ppb	Maximum ppb
Potassium	100	100	6,530	8,780	17,600
Calcium	100	100	52,500	64,400	96,000
Vanadium	1	57	<1.0	2.0	7.5
Chromium	0.1	57	<0.1	0.7	12
Manganese	1	71	<1.0	7.7	412
Iron	1	100	18	33.5	17,900
Cobalt	0.1	7	<0.1	<0.1	0.9
Nickel	0.1	100	2.2	9.3	47
Copper	1	93	<1.0	7.1	64
Zinc	1	100	12	26	3,620
Molybdenum	1	79	<1.0	4.1	15
Silver	1	7	<1.0	<1.0	2.4
Cadmium	0.1	36	<0.1	<0.1	5
Lead	0.1	71	<0.1	2.7	63
Titanium	1	36	<1.0	<1.0	33
Gallium	0.1	29	<0.1	<0.1	0.9
Rubidium	0.1	93	<0.1	6.1	11
Strontium	0.1	100	91	432	604
Tin	0.3	21	<0.3	<0.3	7.3
Antimony	0.4	21	<0.4	<0.4	9.8
Barium	2.5	93	<2.5	35.5	77
Thallium	0.3	7	<0.3	<0.3	0.5
Arsenic	0.5	93	<0.5	2.3	9.5
Selenium	1	29	<1.0	<1.0	2.5

National Interim Primary Drinking Water Regulations. This was the value of 63 μg/l for lead, which was obtained in one sample. Nevertheless, it is clear from Table 10 that indeed a wide range of inorganic elements and concentrations can be detected in renovated wastewaters, as they certainly can in typical public water supplies.

An attempt to develop a framework for assessing which among such a wide range of constituents might on some regular basis constitute a problem was developed by Englande and Reimers(2). They defined an exceedance ratio (E.R.) as the number of samples surpassing potable water quality, divided by the total number of samples evaluated. They then applied this to several constituents analyzed in effluents from five advanced wastewater treatment systems. Table 11 presents the data for those constituents with positive E.R. values. As shown there, ammonia generally had a high value, and chromium, arsenic, and iron appear frequently in the table. It was noted that those facilities that employed lime treatment reported the highest and most consistent reduction in heavy metal concentrations. Although these exceedence ratios do not by themselves constitute a decision-making tool for monitoring, they do point out some of the consistent problems that can be found and may help to focus on those which should receive high priorities in developing such schemes. That is, experience is growing among the various studies of advanced wastewater treatment systems, and their collective results should be examined in the planning of similar systems for renovation and reuse.

It is probably important in developing monitoring strategies to utilize the fact that many constituents will follow in time a distribution such as a log normal one, as discussed in the previous section for the Water Factory 21 study. Thus, based on actual experience, some constituents will show wide

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TABLE 11 From Englande and Reimers, Ref. 2

Potable Water Quality Exceedance Ratios (E.R.) for AWT Plant Spot Survey

LAKE TAHOE			BLUE PLAINS						ORANGE COUNTY		
			System 1			System 2					
Parameter	Median	E.R.	Parameter	Median	E.R.	Parameter	Median	E.R.	Parameter	Median	E.
NH_3-N	15 mg/1	13/13	TDS	524 mg/1	3/3	Se	10 µg/1	1/6	NH_3-N	14.2 mg/1	6/
Se	16 µg/1	13/13	CCE	1300 µg/1	2/2	NO_3-N	0.5 mg/1	1/6	TDS	937 mg/1	6/
Phenol	5 µg/1	7/12	NH_3-N	0.65 mg/1	2/3	Phenol	<5 µg/1	1/6	Cr	57 µg/1	5/
CCE	650 µg/1	3/8	Phenol	<5 µg/1	1/2				NO_3-N	11.3 mg/1	5/
Fe	140 µg/1	3/13	Cr	19 µg/1	1/3				Phenol	<5 µg/1	1/
As	<10 µg/1	2/13	Pb	19 µg/1	1/3						
Cd	<1 µg/1	1/13									
TDS	414 mg/1	1/13									

DALLAS			POMONA								
			System 1			System 2			System 3		
Parameter	Median	E.R.	Parameter	Median	E.R.	Parameter	Median	E.R.	Parameter	Median	E.R
Phenol	7.2 µg/1	6/8	TDS	513 mg/1	7/9	NH_3-N	7.0 mg/1	8/9	NH_3-N	4.7 mg/1	9/9
Se	35 µg/1	5/8	NH_3-N	2.0 mg/1	5/9	TDS	538 mg/1	6/9	TDS	582 mg/1	8/9
TDS	478 mg/1	3/8	Se	<10 µg/1	5/9	Phenol	<5 µg/1	3/9	Cr	55 µg/1	5/9
As	21 µg/1	2/7	CCE	650 µg/1	4/8	NO_3-N	2.7 mg/1	3/9	NO_3-N	8.0 mg/1	4/9
NH_3-N	0.08 mg/1	2/8	Phenol	<5 µg/1	3/9	As	<10 µg/1	2/9	Phenol	5 µg/1	3/9
CCE	200 µg/1	1/7	Cr	30 µg/1	2/9	CCE	340 µg/1	1/8	CCE	400 µg/1	3/9
Cr	4 µg/1	1/8	NO_3-N	4.5 mg/1	2/9	Fe	40 µg/1	1/9	Ag	41 µg/1	2/9
Fe	93 µg/1	1/8	Fe	7.9 µg/1	2/9						
			Hg	0.31 µg/1	2/9						
			Mn	0.0 µg/1	1/9						

Lake Tahoe - Trickling filter (TF), nitrifying activated sludge (NAS), high lime coagulation (HLC) and clarification (C) filtration (F), carbon adsorption (CA).
Blue Plains: System 1 - Low lime clarification (LLC), breakpoint chlorination (BC), CA, dual media filtration.
System 2 - LLC, dispersed growth nitrification, denitrification, CA, mixed media filtration.
Orange County - TF, HLC and C, ammonia stripping, F, activated carbon (AC).
Dallas - Activated sludge (AS), HLC and C, F, CA.
Pomona: System 1 - AS, AC. System 2 - AS, AC, chlorination, AC. System 3 - AS, AC, ozonation, AC.

concentration distributions, and others more narrow ones. If the distribution is likely to be wide and/or approach a concentration that could be of health concern, such a constituent becomes a logical candidate to monitor. The next question that arises is what action should be taken when specific high concentrations are reached. Clearly, when a level related to an adverse health impact is attained this requires specific action. However, such a statement needs elaboration. A constituent which is of concern primarily from the impact of chronic exposure (e.g., lifetime), should be permitted to exceed at times the average permissable adverse chronic limit. In such a case the actual time distribution for such an element should be used to predict the fraction of time (and its uncertainly range) that the constituent is likely to exceed some predetermined value. When it does, this could signal the need for additional sampling, and then judgments made as to whether indeed the time distribution concentrations have increased to the point that the mean human exposures have become unacceptably high.

Finally, the question arises as to the selection of the most useful and cost-effective set of inorganic constituents to monitor regularly in reusing renovated wastewater for potable purposes, and the frequency of such monitoring. Thus, for example, should one monitor simply those inorganics for which there are MCL's specified in the EPA National Interim Primary Drinking Water Regulations? The answer should logically be that, if an exhaustive preliminary study (e.g., a pilot plant) shows that the renovated product is highly unlikely to have any such constituents at concentrations that are unusual in relation to the experience of our currently acceptable public water supplier using "natural" sources, then there is no reason why the monitoring requirements should be any more stringent for the renovation system. This conclusion might require modification if there is an engineering judgment that there is a greater likelihood of failure of the treatment chain.

If, on the contrary, the preliminary study shows the presence of unusually high concentrations of inorganics in comparison with those normally encountered in public water supplies, then judgments must be made, both about their possible adverse health impacts and monitoring strategies. Having done the former, the latter could be based, as described above, on knowledge of their time distributions and the average exposures, whether for lifetime or shorter periods, which are tolerable. Such an approach is predicated on the basis that a renovated wastewater supply for potable use need not intrinsically constitute an unusual hazard. Clearly the best available and protected raw water source should be utilized in every instance, but situations may be encountered where the renovated wastewater may indeed be that source. In such a case a monitoring strategy for inorganic chemicals could be developed that is both practicable and also does not involve an unacceptable risk to the public health.

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